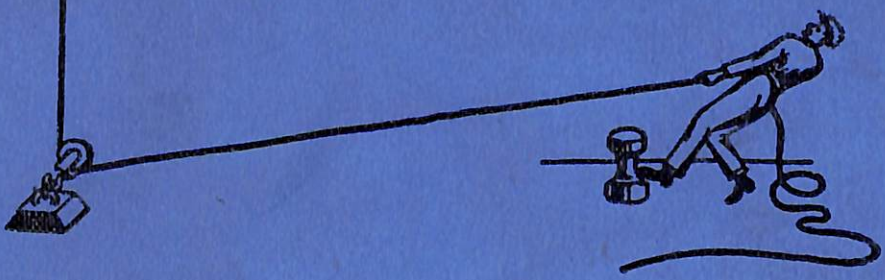
EVERYDAY MECHANICS

GILMOUR & CLARK



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EVERYDAY MECHANICS

by

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and

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PREFACE

THE aim in compiling this book has been to make it a pupil's book. As little information as possible has been given to the pupil, thus preventing him from simply copying. He must acquire information for himself.

The matter is elementary and mainly experimental, dealing with simple ideas and machines met with in everyday life.

An attempt has been made to make the pages more lively by using illustrations showing the machines in operation and showing practical applications of principles. Incidentally, the pupil takes a much greater interest in his own book when the illustrations are incorporated in it and this can be fairly quickly accomplished by copying them on to tracing paper which can then be fixed in its proper place.

The actual units to be employed are in some cases omitted to allow each individual to suit himself.

The following is quoted from "Principles of Mechanics," by T. M. Goodeve, published in 1883 :—

"There is a distinction which has been preserved in books on mechanics, as carefully as if it were of great value, viz. : the separation of levers into three kinds or classes. . . . No practical mechanic cares about these distinctions ; the turning effect of a force is represented by its moment . . . and after this ONE idea is grasped and the position of the fulcrum is ascertained, the subject matter is exhausted."

However, the classification of levers has been included for those who prefer it for teaching purposes. (Pages 18-25 inclusive.)

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A three years' course which is mainly experimental, dealing with simple ideas and machines met with in every day life.

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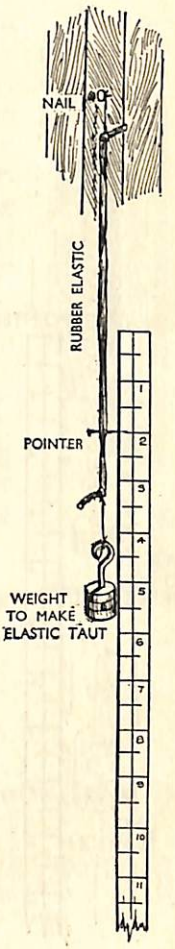
EVERYDAY MECHANICS

Experiment.—**To study the stretching of rubber.**

Arrange the apparatus as shown in the diagram. Note the reading shown by the pointer. Fix a weight on to the end of the rubber. What happens to the rubber? Again note the position of the pointer.



Put the results in a table as shown.

1st Position of pointer	Weight used	2nd Position of pointer	Elongation of rubber

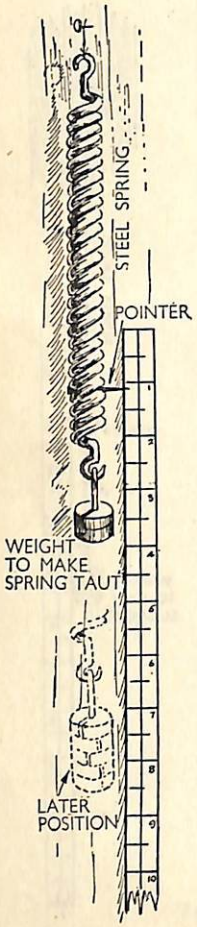
Repeat the experiment twice, each time adding an equal weight and each time noting the position of the pointer.

CONCLUSION.—Each equal weight makes the rubber stretch an {**equal** / **unequal**} **amount.**

Definition.—**A substance is said to be elastic if it can be stretched and then returns to its former size.**

Experiment.—**To study the stretching of a spring.**

Arrange the apparatus as shown in the diagram. Note the reading shown by the pointer. Fix a weight on to the end of the spring. What happens to the spring? Again note the position of the pointer.



Put the results in a table as shown.

1st Position of pointer	Weight used	2nd Position of pointer	Elongation of spring

Repeat the experiment twice, each time adding an equal weight and each time noting the position of the pointer.

CONCLUSION.—Each equal weight makes the spring stretch an {**equal** / **unequal**} **amount.**

HOOKE'S LAW.

When an elastic material is stretched, the elongation is proportional to the load (or stretching force).

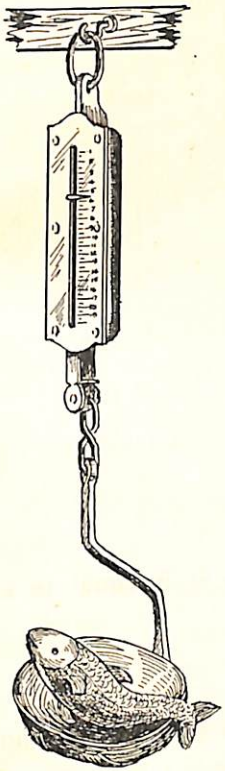


FIG. 1

THE SPRING BALANCE

Figure 1 shows a spring balance used by fishmongers.

To construct a spring balance.

Arrange the apparatus as shown in figure 2. Make a mark on the blank paper exactly at the tip of the pointer. Put a weight on to the end of the spring and again make a mark on the paper at the tip of the pointer. Repeat this twice, each time adding an equal weight and each time marking the position of the tip of the pointer.

What do you notice about the distances between the marks?

Without using any more weights, put marks on the paper showing where the pointer would reach if other three equal weights were added one at a time.

Find the weight of an object, using this apparatus.

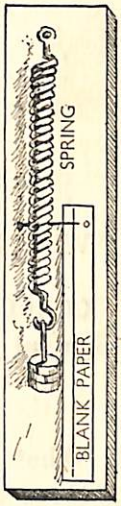


FIG. 2

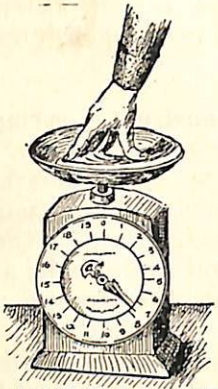
Definition.—**A force is a push or a pull.**

Experiment.—**To show how the size or magnitude of a force is measured.**

Instead of adding weights to a spring balance, pull the spring by hand until the pointer moves any number of spaces.

The pull on the spring is equal to a weight of —— ——.

Push the pan of a household (or compression spring) balance until the pointer moves to any number.



HOUSEHOLD BALANCE

What is the magnitude of the push?

CONCLUSION.—A force is measured by saying it is equal to a weight of so many .....

Questions.

1. What is meant by saying that a substance is elastic? Name three examples.
2. State Hooke's law. What machine in everyday use is based on this law?
3. Hooke's law is also true for wires (within small limits). (*a*) Calculate the elongation of a wire per lb., if a 5-lb. weight stretches the wire ·15 inch. (*b*) What is the length of a wire when stretched by a 10-lb. weight if its length is 136 ins. when stretched by a 1-lb. weight and 136·1 ins. when stretched by a 2-lb. weight?

4. In studying the stretching of an elastic material, the following results were obtained : —

Load	1st Position of pointer	2nd Position of pointer	Elongation
·4 lb.	40 ins.	41·3 ins.	
·8 lb.	41·3 ins.	42·6 ins.	
1·2 lbs.	42·6 ins.	43·9 ins.	
1·6 lbs.	43·9 ins.	45·2 ins.	
2·0 lbs.	45·2 ins.	46·5 ins.	

Calculate the elongation in each case.

Draw a graph, representing the load on the horizontal axis and the corresponding length of the material on the vertical axis.

From your graph find (*a*) the length when the load is 2·4 lbs. and (*b*) the load when the length is 43·25 ins.

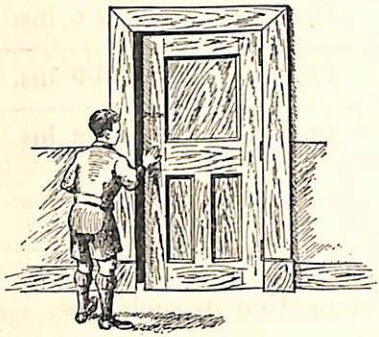
5. What is a force ?

MOMENTS

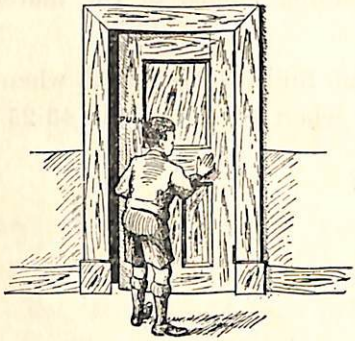
Definition.—**The moment of a force is its turning value.**

Experiment.—**To study the moment of a force.**

Push a door at a point as far away from the hinges (or turning point) as possible so that the door just opens or turns on its hinges.



Apply an equal push near the hinges.

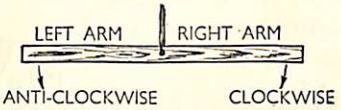


Does the door turn this time?

CONCLUSION.—The moment of a force applied near the turning point (or fulcrum) is {greater / less} **than the moment of the force applied further from the fulcrum.**

Experiment.—**To show how the moment of a force is measured.**

Arrange a rod as shown in the diagram so that it is exactly balanced.



Put any weight on the right arm. Does the rod turn clockwise or anti-clockwise ?

Take off this weight and put any weight on the left arm. Does the rod turn clockwise or anti-clockwise.

Put any weight on the right arm and another weight on the left arm so that the rod turns clockwise. Put the results in a table as shown and complete the table.

Left Arm			Right Arm			How the rod turns
Weight used	Distance of weight from fulcrum	Weight × Distance	Weight used	Distance of weight from fulcrum	Weight × Distance	

Repeat the experiment but arrange the weights so that the rod turns anti-clockwise.

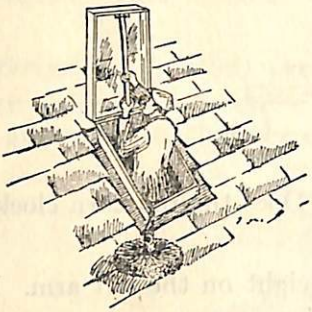
Arrange the weights this time so that the rod is balanced.

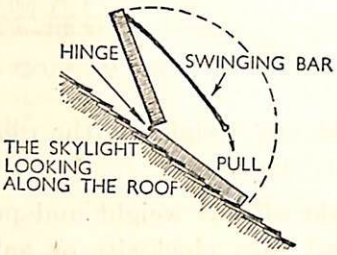
Examine the results in the third, sixth and seventh columns.

CONCLUSION.—The moment is measured by multiplying the weight by its .... from the fulcrum.

MORE ABOUT MOMENTS.

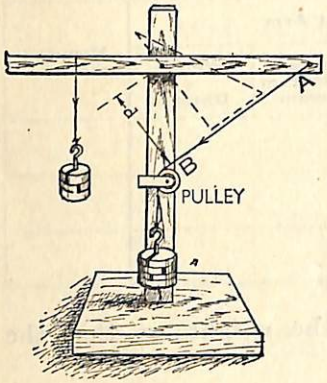
In closing the sky-light shown here, is the direction of the pull at right angles to the sky-light itself?





Experiment.—**To show more exactly how the moment of a force is measured.**

Balance a rod and on to the right arm put a weight, arranging it as shown. Put an equal weight on the left arm so that the rod is again balanced.



Calculate the moment anti-clockwise.

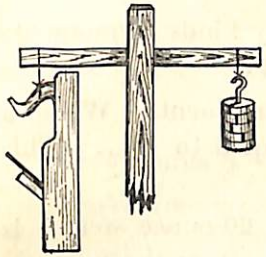
Measure the perpendicular distance from the fulcrum to the string AB. Multiply this by the weight used.

CONCLUSION.—The moment is measured by multiplying the force by the .... distance from the fulcrum to the line along which the force acts.

NOTE.—In the previous experiment, the pull on the rod of each weight was {vertical / not vertical}, and the distance measured was {horizontal. / not horizontal.}

Was the moment measured correctly?

Experiment.—**To find the weight of an object using one weight.**



Balance a rod. Put any weight on the right arm and the object on the left arm so that the rod is again balanced.

What do you know about the moment clockwise and the moment anti-clockwise ?

Find the moment clockwise and calculate the weight of the object.

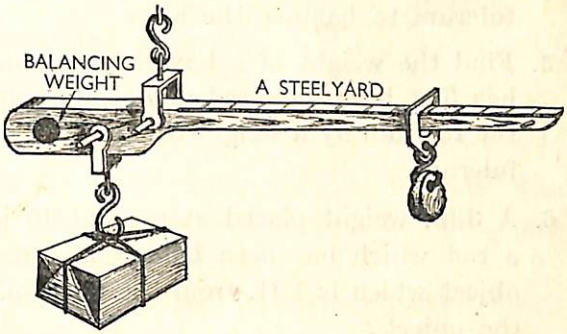
CONCLUSION.—The weight of the object = ...

THE STEELYARD.

The sketch shows a steelyard, an appliance used for finding the weights of objects.

To graduate a steelyard.

Balance a rod. Put a weight on the left arm a short distance from the fulcrum. Put an object on the right arm so that the rod is again balanced. Mark the position of the object.



Add an equal weight to the first one, keeping it in the same position and move the object until the rod is again balanced.

Again mark the position of the object.

Repeat this a number of times, adding an equal weight to the weights on the left arm each time.

What do you notice about all the spaces on the right arm ?

Find the weight of an object using your steelyard.

QUESTIONS.

1. What does the moment mean? How many kinds of moments are there? How is the moment measured?
2. Write out and complete the following statement:—When a rod is balanced, the moment clockwise is equal to ..... (This is called the Law of Moments.)
3. A rod is balanced at its mid-point and a 20-ounce weight is attached to the right arm at a point 25 ins. from the fulcrum. A weight of 50 ounces is attached to the left arm at a point 20 ins. from the fulcrum. (*a*) Find how the rod turns. (*b*) At what point would the 50-ounce weight need to be attached, to balance the rod?
4. A rod is balanced at its mid-point. A 10-lb. weight is 3 ft. from the fulcrum. What weight must be placed 15 ft. from the fulcrum to balance the rod?
5. Find the weight of a boy if he is balanced on a beam (which has first been balanced at its mid-point) at a point 6 ft. from the fulcrum by a weight of 8 st., $4\frac{1}{2}$ ft. on the other side of the fulcrum.
6. A 3-lb. weight placed at a point 10 ins. from the fulcrum of a rod which has been balanced at its mid-point, balances an object which is 1 ft. from the fulcrum. What is the weight of the object?
7. A rod is balanced at its mid-point. A string is fixed to the right arm at a point 4 ft. from the fulcrum. A 10-lb. weight is fixed to the string. (*a*) Find the moment.

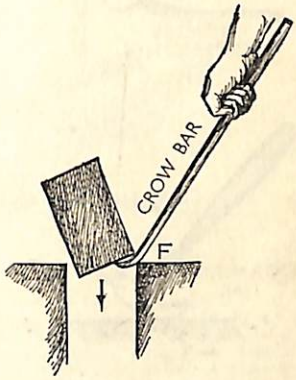
   Find graphically the moment when the string makes an angle of (*b*) 60°, (*c*) 30° with the rod. (*d*) What do you notice about the moment as the angle becomes smaller? (*e*) What would be the moment when the angle is 0°?

LEVERS.

Definition.—**A lever is a rigid body capable of turning about a fixed point. The fixed point is called the fulcrum.**

To examine a lever.

The sketch shows a crowbar. Is it rigid? Is there a fulcrum? Where is it? The crowbar is therefore a .....



The force used in raising the object is called the effort. The object lifted (or the resistance overcome) is called the load.

In what direction would the load turn the bar? In what direction would the effort turn the bar?

When the bar is balanced (*i.e.* the load is raised), what do you know about the moment clockwise and the moment anti-clockwise?

If the load weighs 100 lbs. and is 6 ins. from the fulcrum, what is the effort required to balance the load if the effort is applied 5 ft. from the fulcrum?

How many times is the load greater than the effort? This is called the mechanical advantage.

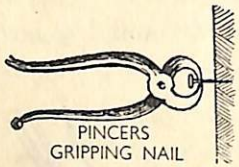
In this example, the load is $\left\{\begin{matrix}\text{greater}\\\text{less}\end{matrix}\right.$ than the effort but the load moves more $\left\{\begin{matrix}\text{quickly}\\\text{slowly}\end{matrix}\right.$ than the effort.

Definition.—**The mechanical advantage is the number of times the load is ..... than the effort.**

100
4?

To examine other levers.

The following sketches show other examples of the lever. Answer the questions in the table shown at the end of the sketches.



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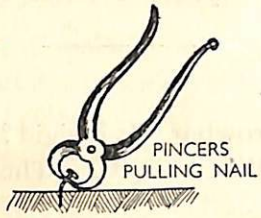

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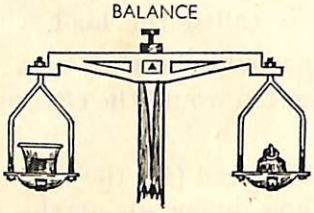

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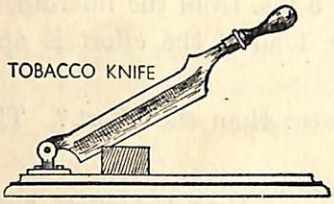

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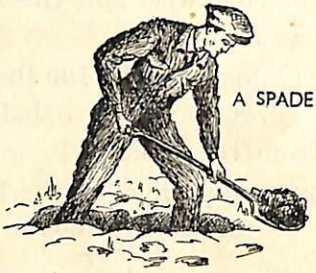

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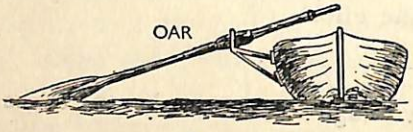

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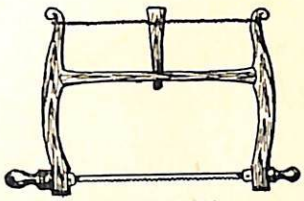

BOW SAW

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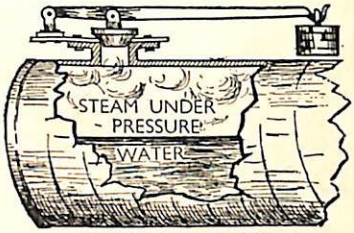
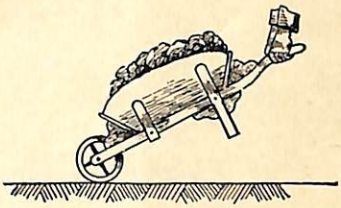


BOILER SAFETY VALVE

13



WHEEL BARROW

14

Name of lever	Where is the fulcrum ?	What is the load ?	Is the load or the effort further from the fulcrum ?	Is the load or the effort the greater when the lever is balanced ?	Does the effort or the part of the lever where the load is move more quickly ?

Examine the answers in the last two columns.

When the load is greater than the effort, the part of the lever where the load is moves more { quickly / slowly } than the effort.

When the load is equal to the effort, the part of the lever where the load is moves .... as the effort.

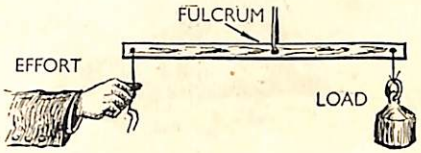
When the load is less than the effort, the part of the lever where the load is moves more { quickly / slowly } than the effort.

LEVERS (ALTERNATIVE METHOD).

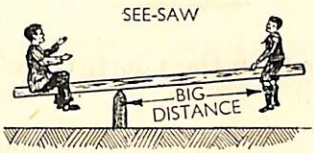
Levers are sometimes divided into classes or orders according to the positions of the load, fulcrum and effort.

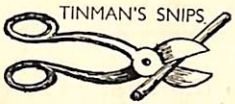
To examine levers of the first order.

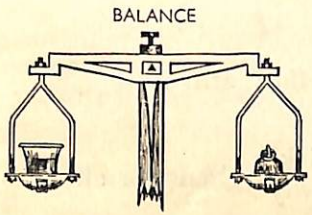
The diagram below shows the positions of the load, fulcrum and effort in levers of the first order.

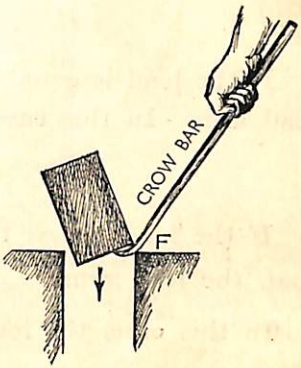


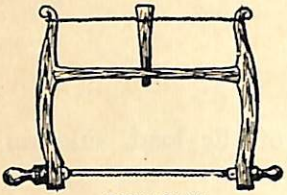
Well known examples of this order are shown.



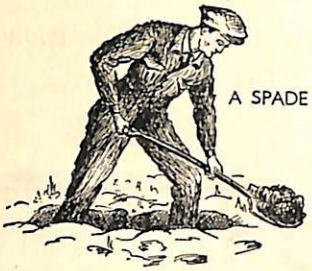








BOW SAW



A SPADE

Trace these diagrams on to tissue paper and in each case indicate where the load is with an **L** and where the fulcrum is with an **F.** Show by an arrow or arrows where and how the effort is applied.

If the load is greater than the effort, the effort arm is {longer / shorter} than the load arm.

In this case the load moves more {quickly / slowly} than the effort.

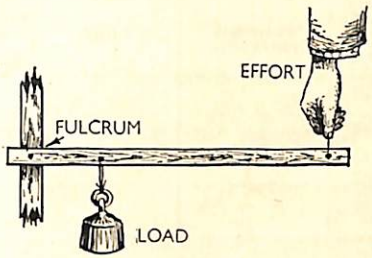
If the load is equal to the effort, the effort arm is .... to the load arm. In this case, the load moves .... as the effort.

If the load is less than the effort, the effort arm is {longer / shorter} than the load arm.

In this case, the load moves more {quickly / slowly} than the effort.

To examine levers of the second order.

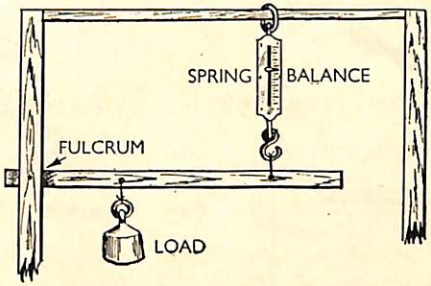
The diagram below shows the positions of the load, fulcrum and effort in levers of the second order.



In this order, the load is between the fulcrum and the effort.

Experiment.—**To show that when a lever of the second order is balanced, the moments are equal.**

Balance a rod and arrange the apparatus as shown in the diagram, so that the rod is again balanced.



Would the weight itself make the rod turn clockwise or anti-clockwise? Would the pull on the spring balance itself make the rod turn clockwise or anti-clockwise?

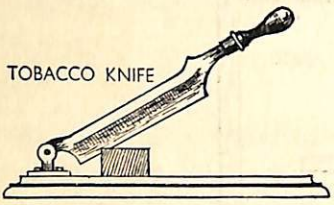
Find the distance of the weight and of the spring balance from the fulcrum. Put the results in a table as shown below and complete the table.

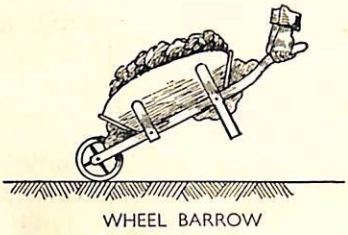
Load	Distance of load from fulcrum	Moment clockwise	Effort	Distance of effort from fulcrum	Moment anti-clockwise

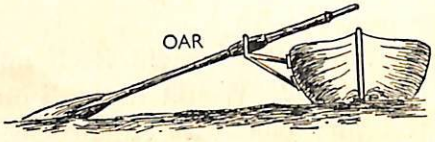
Repeat the experiment twice.

CONCLUSION.—When a lever of the second order is balanced, the moment clockwise .... the moment anti-clockwise.

Examples of this order are shown.





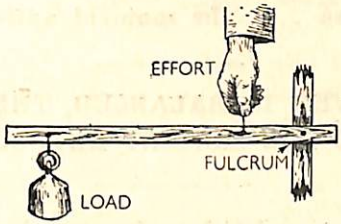


Trace these diagrams on to tissue paper and in each case indicate where the load is with an **L** and where the fulcrum is with an **F.** Show by an arrow or arrows where and how the effort is applied.

Since the load is between the fulcrum and the effort, the effort arm is always {longer / shorter} than the load arm. The load is therefore always {greater / less} than the effort and the load moves more {slowly / quickly} than the effort.

To examine levers of the third order.

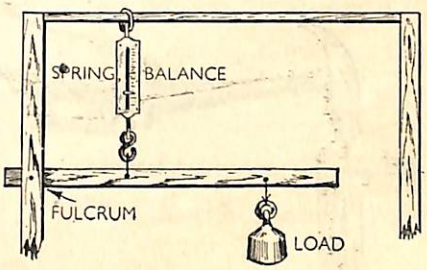
The diagram below shows the positions of the load, fulcrum and effort in levers of the third order.



In this order, the effort is between the load and the fulcrum.

Experiment.—**To show that when a lever of the third order is balanced, the moments are equal.**

Balance a rod and arrange the apparatus as shown in the diagram so that the rod is again balanced.



Would the weight itself make the rod turn clockwise or anti-clockwise? Would the pull on the spring balance itself make the rod turn clockwise or anti-clockwise? Find the distance of the weight and of the spring balance from the fulcrum.

Put the results in a table as shown below and complete the table.

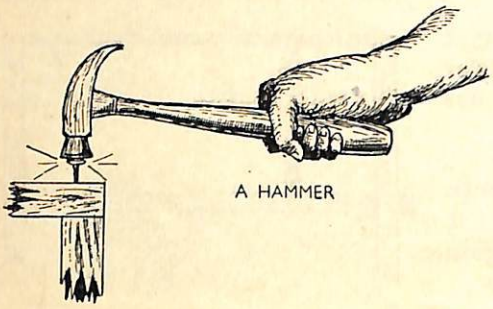
Load	Distance of load from fulcrum	Moment clockwise	Effort	Distance of effort from fulcrum	Moment anti-clockwise

Repeat the experiment twice.

CONCLUSION.—When a lever of the third order is balanced, the moment clockwise .... the moment anti-clockwise.

WHEN ANY LEVER IS BALANCED, THE MOMENT CLOCKWISE IS EQUAL TO THE MOMENT ANTI-CLOCKWISE.

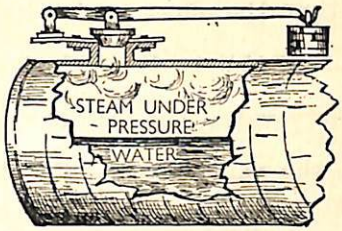
Examples of this order are shown.



A HAMMER

FORCEPS

H AND VICE



BOILER SAFETY VALVE

BRACE AND BIT

Trace these diagrams on to tissue paper and in each case indicate where the load is with an **L** and where the fulcrum is with an **F**. Show by an arrow or arrows where and how the effort is applied.

Since the effort is always between the load and the fulcrum, the effort arm is always {longer / shorter} than the load arm. The load is therefore always {greater / less} than the effort and the load moves more {quickly / slowly} than the effort.

NOTES ON LEVERS.

Levers like the crowbar and wheelbarrow are used because the load is {less / greater} than the effort. In some cases, however, the load is less than the effort and the following examples show why such levers are used.

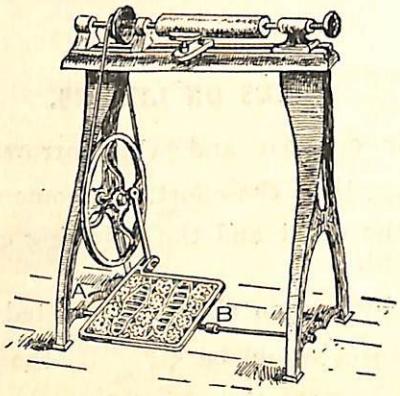
Suppose an easily broken object were lifted with nut crackers. The grip on the object would be {greater / less} than the effort. What would probably happen to the object?

If, however, the object is lifted with forceps, the grip on the object is {greater / less} than the effort (which itself may be very small) and the forceps thus enable us to hold an object very gently.

In the steam safety valve, the load is {greater / less} than the steam pressure. Therefore the valve mechanism can be made light, thus saving material and space.

Sometimes speed is required. In the lathe shown, where is the fulcrum of the treadle? If the lathe is worked with one foot, the foot is placed across the fulcrum and the effort is applied with the ball of the foot. Is the effort or the load the greater? Why? Does the effort or the part of the lever where the load is, move more quickly? The effort is now applied with the heel. Is the effort or the load the greater? Why? Does the effort or the part of the lever where the load is move more quickly?

In both cases, the part of the lever where the load is moves more {quickly / slowly} than the effort itself, but the load is {greater / less} than the effort.



THE BELL CRANK LEVER.

The picture shows a gong being operated by pulling on a wire. The wire changes from the vertical to the horizontal and this is brought about by using a bell crank lever.

What does the bell crank do to the direction of the pull ?

Experiment.—**To study the bell crank lever.**

Arrange a bell crank lever so that the long arm is horizontal.

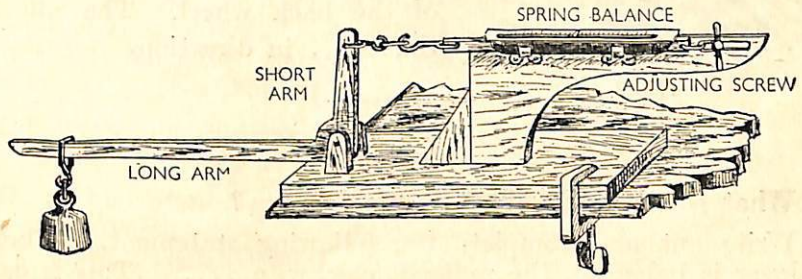


FIG. 1

Take the reading on the spring balance. Put a weight on the long arm and adjust so that this arm is again horizontal. Again take the reading on the spring balance.

Put the results in a table as shown below.

Weight used	Distance of weight from fulcrum	Moment anti-clockwise	Extra reading on balance	Distance of balance from fulcrum	Moment clockwise

Repeat the experiment twice, altering the weight and its distance from the fulcrum.

CONCLUSION.—When a bell crank lever is balanced, the moment clockwise .... the moment anti-clockwise.

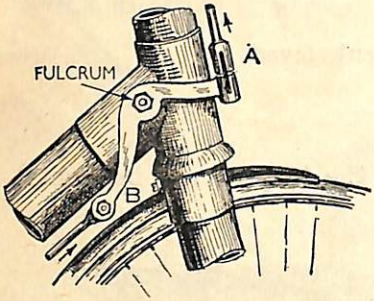


FIG. 2

An interesting application of the bell crank lever is shown in Fig. 2. When the grip at the handle bar lifts rod A, the lever turns at the fulcrum and pulls rod B. This rod in turn pulls the brake pads against the rim of the back wheel. The effort is thus .... in direction.

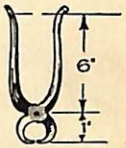
Questions.

1. What is a lever? What is the fulcrum?
2. Write out and complete the following statement. When a lever is balanced, the moment clockwise ..... (This is called the Law of Moments or the Law of the Lever.)

3. What does mechanical advantage mean? Find the mechanical advantage (*a*) if a load of 200 lbs. is balanced by an effort of 40 lbs. weight, and (*b*) if a load of 50 lbs. is balanced by an effort of 100 lbs. weight.

4. Name three examples of the lever and in each case state what the load is and the position of the fulcrum. Draw diagrams where they would help your explanations.

5. What is the grip that nippers of the dimensions shown will take on a nail, if the effort applied at the ends of the nippers is equal to a 10-lb. weight?



6. (*a*) A bag of cement weighing 1 cwt. is placed in a wheel barrow as near the front as possible. If the load is 1 ft. from the axle, what effort is required just to raise the cement, if the shafts of the barrow are gripped at a distance of 3 ft. from the axle? (Neglect the weight of the barrow.)

   (*b*) What is the mechanical advantage?

   (*c*) The cement is now put as near the back of the barrow as possible. It is now 2 ft. from the axle. What effort is required now?

   (*d*) What is the mechanical advantage?

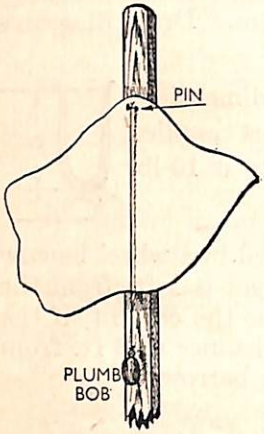
7. Write out and complete the following statements :—When the load is greater than the effort, the part of the lever where the load is moves more .... than the effort. When the load is less than the effort, the part of the lever where the load is moves more .... than the effort.

8. (*a*) Write out and complete the following statement :—A bell crank lever is used to .... the direction of a force.

   (*b*) A bell crank lever has arms 3 ft. and 1 ft. long. If the long arm is loaded at its end with a weight of 4 tons, what effort is needed at the end of the short arm to balance the lever, the effort being applied at right angles to the short arm?

THE CENTRE OF GRAVITY.

Experiment.—**To find the centres of gravity of regular and irregular pieces of cardboard.**



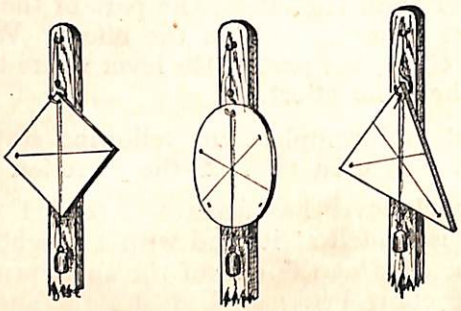
Suspend an irregular piece of cardboard as shown in the diagram, taking care that it can swing freely.

Hang a plumb line on to the pin and make a dot low down on the cardboard and exactly under the plumb line. Join the dot to the pin hole, extending the line as far as possible in each direction.

Repeat this twice, placing the pin at different positions but near the edge of the cardboard.

What do you notice about the three lines? Turn the cardboard over and rest it with this point on the tip of your finger. What do you notice? This point is the centre of gravity.

Repeat the experiment with a square, a circular and a triangular piece of cardboard.



CONCLUSION.—**The centre of gravity is the ....**

Experiment.—**To find when an object overbalances.**

Construct a box similar to that shown in Fig. 1. Load the box at one end, taking care that the loading cannot move.

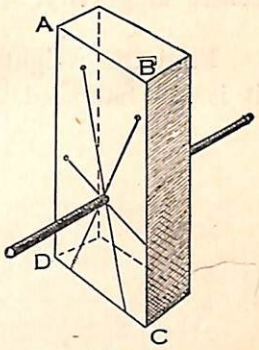


FIG. 1

Find the centre of gravity of the box in the same way as in the previous experiment, using the face **ABCD.**

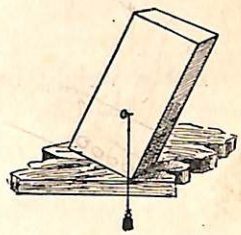
Put a stiff wire through a hole bored through the box at its centre of gravity and hang a plumb line on to this wire.

Stand the box on its end, near the edge of a table, so that the plumb line is freely suspended. Tilt the box sideways until it is exactly balanced.

Where is the plumb line when the box is exactly balanced? Where is it when the box overbalances?

Repeat the experiment with the box upside down. Again notice where the plumb line is when the box is exactly balanced and when it overbalances.

Does the box need to be tilted as much this time before it overbalances?



CONCLUSION.—An object overbalances when the plumb or vertical line from its centre of gravity falls .... the base of the object.

Examine the three following sketches. Note the centres of gravity (*) and state why balance is maintained in each case.

Experiment.—**To show that the weight of an object acts at its centre of gravity.**

Find the weight of a rod and arrange it as in Fig. 1, so that it is not balanced.

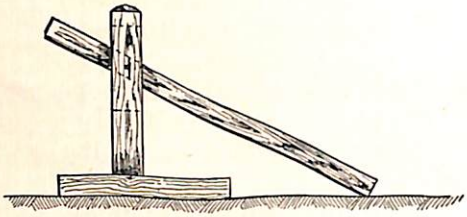


FIG. 1

Put a weight on the rod so that it is now balanced (Fig. 2).

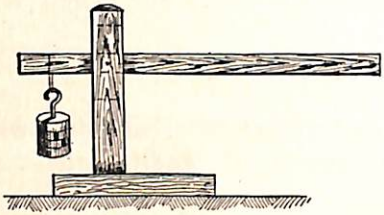


FIG. 2

What do you know about the moment clockwise and the moment anti-clockwise? Find the moment due to the weight used. Divide this moment by the weight of the rod. At what distance from the fulcrum can we say the weight of the rod acts? What point in the rod is this?

CONCLUSION.—The weight of an object acts at .....

EQUILIBRIUM.

Experiment.—**To examine three states of equilibrium.**

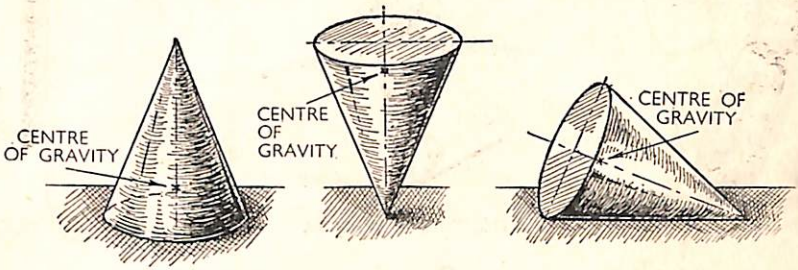


FIG. 1 FIG. 2 FIG. 3

Place a cone as shown in Fig. 1. Tilt it a little. Is the centre of gravity raised or lowered? Does the cone fall over or return to its original position when it is let go?

Try to balance the cone as in Fig. 2. What happens to the cone when you try this? Is the centre of gravity raised or lowered?

Place the cone as in Fig. 3 and give it a gentle push. Is the centre of gravity raised or lowered? Does the cone fall, return to its original position, or simply remain where pushed?

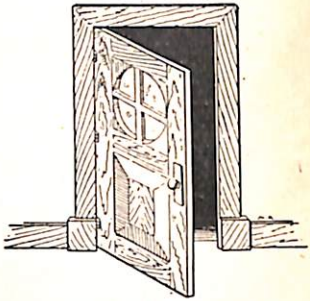
CONCLUSION.—A body is said to be in stable equilibrium if, when it is tilted a little, it returns to its original position. (The centre of gravity is raised when the body is tilted.)

Write out similar statements for the cone in positions 2 and 3. In 2 it is in unstable equilibrium and in 3 it is in neutral equilibrium.

Examine the three following sketches. Which state of equilibrium does each represent ?

BOXER'S DUMMY

TIGHT-ROPE WALKER



WELL HUNG DOOR

Questions.

1. Write out and complete the following statement. The centre of gravity of an object is the point at which the object .... in any position and it is the point through which the whole .... of the object acts.
2. Describe how to find experimentally, the centre of gravity of a triangular piece of cardboard.
3. Cut out a triangular piece of cardboard. Draw the medians. Balance the cardboard on the tip of a finger. Where is the centre of gravity ?
4. Where is the centre of gravity of (*a*) a rectangular piece of cardboard and (*b*) of a circular piece ?
5. When does an object overbalance ?
6. Explain the following :—
   (*a*) When carrying a heavy object in one hand, the other arm is stretched outwards.
   (*b*) A person with a pack on his back, leans forward.
   (*c*) The modern motor vehicle is low set.
   (*d*) Passengers are not allowed to stand upstairs in buses.

7. What do you know about the state of equilibrium in each of the following cases? :—

   (*a*) An Association football on the ground.

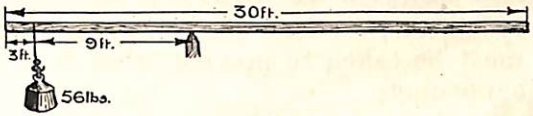
   (*b*) A Rugby football standing on end.

   (*c*) A boy, cycling and trying to stop while sitting on the saddle.

   (*d*) A cylinder standing on its base.

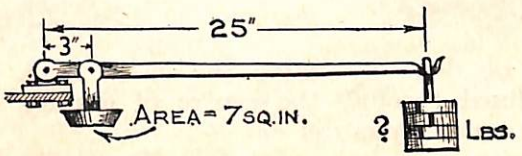
8. A skylight, weighing 6 lbs., is 2 ft. long. Its centre of gravity is 1 ft. from the line of the hinges. What effort is required to hold the window in a horizontal position, if the effort is applied at right angles to the window at a point 2 ft. from the line of the hinges?

9. Find the weight of a uniform beam 30 ft. long which is balanced as shown.

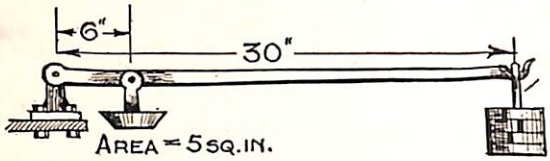


10. In questions 6 (*a*) and 6 (*c*), page 29, no account was taken of the weight of the barrow. If the barrow (without its wheel) weighs 28 lbs. and the centre of gravity of that part of the barrow is $1\frac{1}{2}$ ft. from the axle, find what force the man must actually use just to raise the cement.

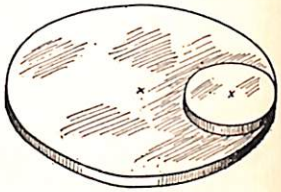
11. Here are given the dimensions of a safety valve. The lever itself weighs $11\frac{1}{2}$ lbs. and its centre of gravity is 12 inches from the fulcrum. The valve weighs 4 lbs. What weight must be put on the lever so that the steam will blow off at 150 lbs. per square inch?



12. At what pressure in lbs. per square inch will the steam blow off with a valve having the dimensions shown here? The lever itself weighs 6 lbs. and its centre of gravity is 11 inches from the fulcrum. The valve weighs 4 lbs. The weight on the lever is 100 lbs.

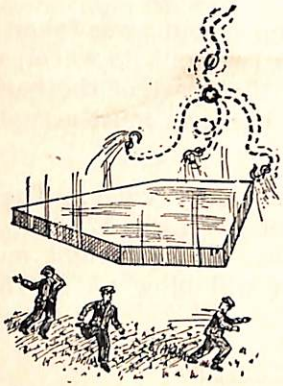


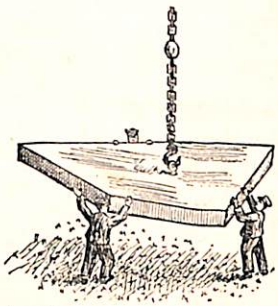
13. Two circular metal plates of equal thickness are fastened together so that their centres are 2 ft. apart. The larger has a radius of 3 ft., while the smaller has a radius of 1 ft. Find thecentre of gravity of the combined plates.



THE CENTRE OF GRAVITY (*continued*).

When heavy objects, for example, plates, are being lifted with a crane, care must be taken to prevent what is shown in the first picture from happening.





This can be done by fixing the chain hook to an eye bolt temporarily fixed through the centre of gravity of the plate as shown in the second picture.

Experiment.—**To find the centre of gravity of a plate composed of a triangular and a square part.**

Draw the plate shown in Fig. 1 to scale. Find graphically G_1, the centre of gravity of the triangular part, and G_2, the centre of gravity of the square part. Join G_1 and G_2 with a straight line.

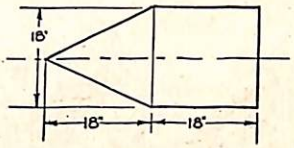


FIG. 1

Suppose a chain is attached to a point in G_1 G_2 (Fig. 2). In what direction does the weight of the triangular part tend to turn the plate? In what direction does the weight of the square part tend to turn the plate? Where must the centre of gravity of the whole plate lie?

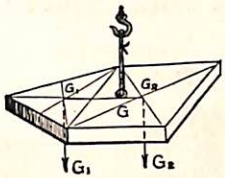


FIG. 2

Let **G**, the centre of gravity of the whole plate, be x feet from G_2. Find the length of G_1 G_2. What is the length of G_1 **G**?

Find the weight of the triangular part and of the square part if the thickness of the plate is **T** feet and the weight of one cubic foot is **W** lbs.

Calculate the moment clockwise and the moment anti-clockwise. What do you know about these moments? Thus find the distance of the centre of gravity from G_2.

CONCLUSION.—The centre of gravity of the whole plate is .... feet from the centre of gravity of the square part of the plate and it lies on the straight line G_1 G_2.

To show what the resultant means.

Here are two horses pulling a load in the same direction.

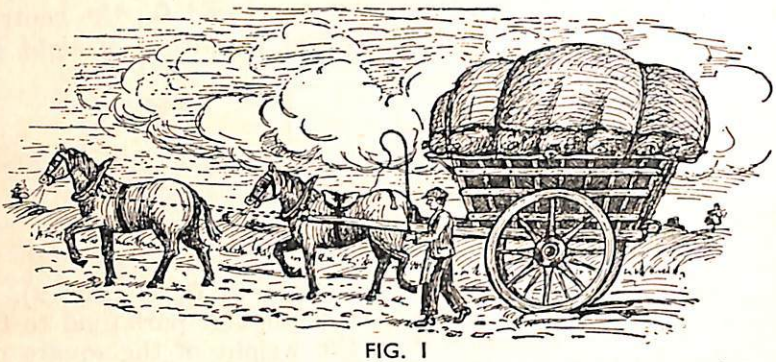


FIG. 1

If each horse pulls with a force equal to a 1-ton weight, what one force would have the same result? This one force is called the resultant.

FIG. 2

In Fig. 2, the two people are pulling in opposite directions. The man on the right is using a force equal to a weight of 12 stones. The youth on the left is using a force equal to a weight of 8 stones. What one force would produce the same result? Would this force need to be applied to the right or to the left? This one force is called the resultant.

CONCLUSION.—The resultant is the one force which produces the same result as a number of forces.

To show what the equilibrant means.

The youth now helped by a boy, is just holding his ground (Fig. 3). Both, however, are unable to move the man. Is the force exerted by the man or the resultant of the forces exerted by the boy and youth the greater?

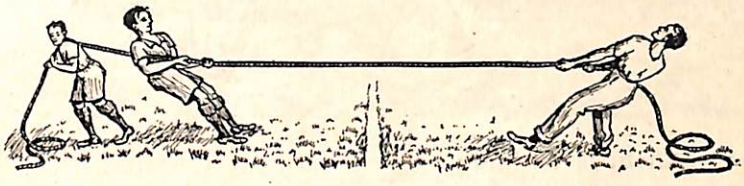


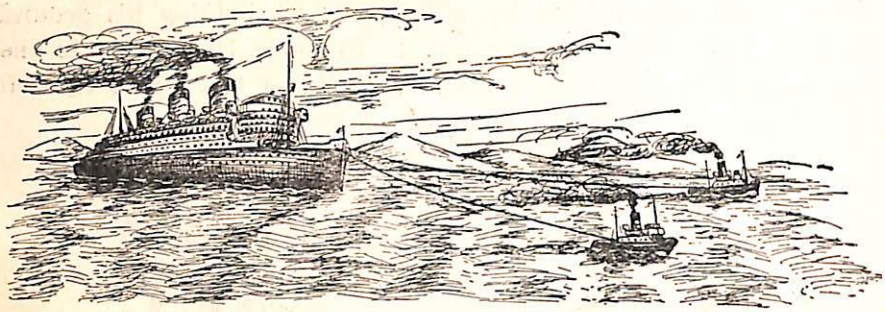
FIG. 3

The force exerted by the man is in the { opposite / same } direction { as / to } the force exerted by the other two. The force exerted by the man is called the equilibrant.

Conclusion.—The equilibrant is the one force which balances the effect of a number of forces. The equilibrant is equal to the .... in magnitude but it is .... in direction.

THE PARALLELOGRAM OF FORCES.

Look at the sketch.



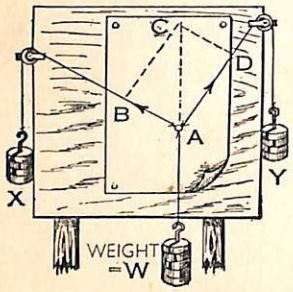
The problem is to find :

(1) the combined (or resultant) force of the tug boats, and
(2) the direction in which the liner moves.

Experiment.—**To find the resultant of two divergent forces acting at a point.**

Arrange the apparatus as shown in the diagram.

What forces balance the weight **W**? Note the magnitude of these forces. Trace the positions of the three strings **AW**, **AB** and **AD** very carefully on the paper. Mark the direction of each force with an arrow. Remove the apparatus.



Taking a unit of length to represent a suitable number of units of force, draw the parallelogram **ABCD**, in which **AB** represents the force **X** and **AD** represents the force **Y**. Join **AC**. What do you notice about the lines **AW** and **AC**?

Measure **AC**. How many units of force does **AC** represent? Would this force balance the weight **W**? In what direction would this force need to be applied?

CONCLUSION.—The force represented by the line .... in magnitude and direction is the resultant of the two forces represented by AB and AD.

Questions.

1. What is (*a*) the resultant?; (*b*) the equilibrant?
2. Write out and complete the following statement. If two forces acting at a point be represented in magnitude and direction by the two adjacent sides of a parallelogram, their resultant is represented in magnitude and direction by .... (This is the Parallelogram of Forces.)
3. Find the magnitude of the resultant of two forces acting at a point in the following examples:—(*a*) Forces of 5 lbs. weight and 10 lbs. weight, the angle between the forces being 60°; (*b*) Forces of 3 lbs. weight and 4 lbs. weight, the angle between the forces being 90°; (*c*) Forces of 4 lbs. weight and 8 lbs. weight, the angle between the forces being 60°.
4. Find the force **B** in the following examples, if two forces **A** and **B** act at a point so that their resultant is **R**:—(*a*) **A** is 30 lbs. weight, **R** is 62·5 lbs. weight, and the angle between **A** and **R** is 30°; (*b*) **A** is 40 lbs. weight, **R** is 70 lbs. weight, and the angle between **A** and **R** is 45°.
5. Find the angle between two forces **P** and **Q**, the resultant of which is **R** in the following cases:—(*a*) **P** is a force of $2\frac{1}{2}$ lbs. weight, **Q** is a force of $3\frac{1}{2}$ lbs. weight, while **R** is 5 lbs. weight; (*b*) **P** is a force of 30 lbs. weight, **Q** is a force of 30 lbs. weight, while **R** is 55 lbs. weight.

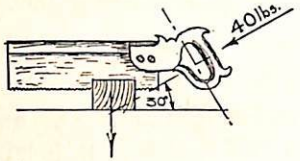
6. Two tugs are towing a ship and the angle between the ropes which are attached to the same point in the ship is 30°. If the forces exerted by the tugs are 400 tons weight and 350 tons weight, find the resultant pull on the ship.

7. A barge is drawn along a canal by two horses. Each horse pulls on a rope, the two ropes being attached to the same point in the barge. Each horse exerts a force of 1 ton weight. If the resultant is $1\frac{1}{2}$ tons weight, find the angle between the ropes.

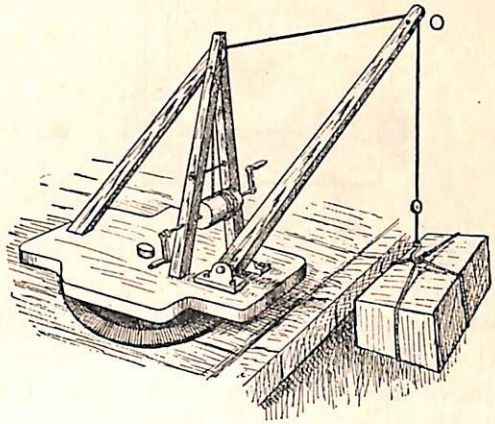
8. (*a*) A rope is fixed to the front of a railway truck. The rope is kept horizontal and a man pulls on the rope with a force of 100 lbs. weight. The rope makes an angle of 20° with the direction of the railway. What is the magnitude of the force which pulls the truck forward?

   (*b*) What does the force do that is not used in pulling the truck forward?

9. A boy pushes his saw with a force of 40 lbs. weight as shown in the diagram. What is the magnitude of the force that causes the saw to travel downwards, *i.e.* that parts the wood?



THE TRIANGLE OF FORCES.



In the crane shown in the sketch, the stout member which thrusts outwards and upwards is called the jib. The chain or rope which holds up the jib is called the tie, while the chain or rope which supports the load is the load chain.

The builder of the crane must know what forces are exerted on the jib and the tie when the crane is loaded to its maximum so that his construction is safe.

How many forces are acting at **O**? Since the point **O** is in equilibrium, what do you know about these forces?

The problem is to find (1) the thrust on the jib and (2) the tension in the tie.

Experiment.—**To study three forces in equilibrium acting at a point.**

Arrange the apparatus as shown in Fig. 1.

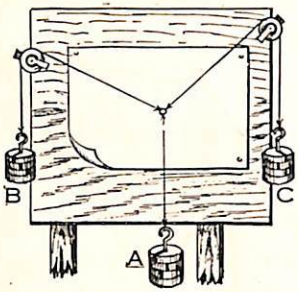


FIG. 1

Trace the positions of the strings very carefully on the paper. Mark the direction of each force with an arrow and note its magnitude. Remove the apparatus and letter the lines as in Fig. 2.

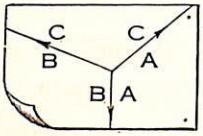


FIG. 2

Take a unit of length to represent a suitable number of units of force. Draw **ab** parallel and equal by scale to the force **AB**. From **b**, draw **bc** parallel and equal by scale to the force **BC**. From **c**, draw a line parallel and equal by scale to the force **CA**.

What do you notice about the end of this last line and the point **a**? Mark the direction of each force with an arrow.

CONCLUSION.—When three forces in equilibrium act at a point, the forces may be represented in magnitude and direction by the sides of a .... taken in order.

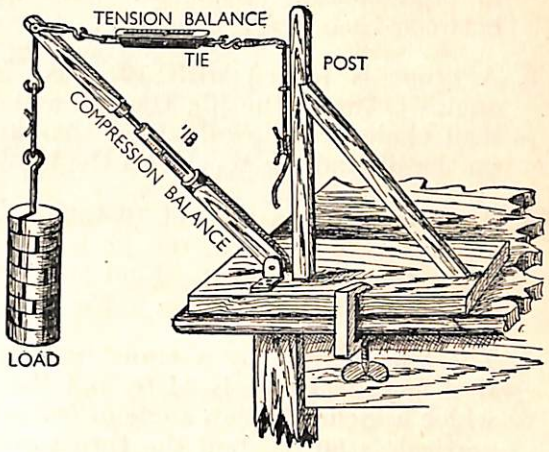
THE TRIANGLE OF FORCES (ALTERNATIVE METHOD).

Here is an interesting method of finding (1) the thrust on the jib and (2) the tension in the tie.

Experiment.— **To study three forces in equilibrium acting at a point.**

Construct a model crane as shown.

Note the reading on each balance. Load the crane. Trace on a sheet of paper the positions of the two strings, the point **O** and the jib of the crane.



Remove the paper and produce the thrust of the jib. Mark the direction of each force with an arrow and letter the lines as in Fig. 1.

Note the reading on each balance and the load used. Find the pull in the tie and the thrust of the jib due to the load used.

Take a unit of length to represent a suitable number of units of force. Draw **ab** parallel and equal by scale to the force **AB.** From **b**, draw **bc** parallel and equal by scale to the force **BC.** From **c**, draw a line parallel and equal by scale to the force **CA.**

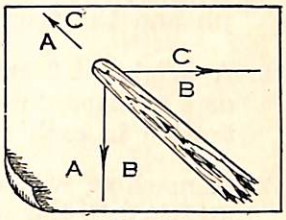


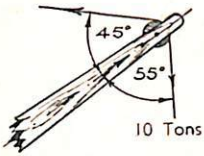
FIG. 1

What do you notice about the end of this last line and the point **a**? Mark the direction of each force with an arrow.

CONCLUSION.—When three forces in equilibrium act at a point, the forces may be represented in magnitude and direction by the sides of a .... taken in order.

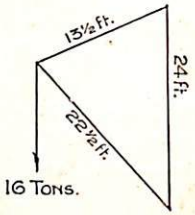
Questions.

1. Write out and complete the following statement. When three forces in equilibrium act at a point, they can be represented in magnitude and direction by .... taken in order. (This is the Triangle of Forces.)



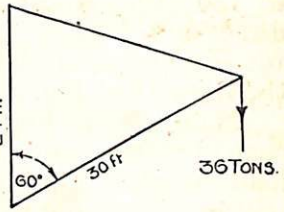
2. Forces of 4 lbs. weight, 8 lbs. weight and 10 lbs. weight act at a point and are in equilibrium. What are the angles between their lines of action?

3. A crane is loaded with 10 tons. The angles between the jib, the tie and the load chain are shown. Find the thrust on the jib and the tension in the tie.



4. A crane carries a load of 16 tons. The vertical pole is 24 ft., the jib is $22\frac{1}{2}$ ft., while the tie is $13\frac{1}{2}$ ft. Find the thrust on the jib and the tension in the tie.

5. The load carried by a crane is 36 tons. If the vertical pole is 24 ft. and the jib, which is inclined at an angle of 60° to the vertical, is 30 ft., find the thrust on the jib and the tension in the tie.



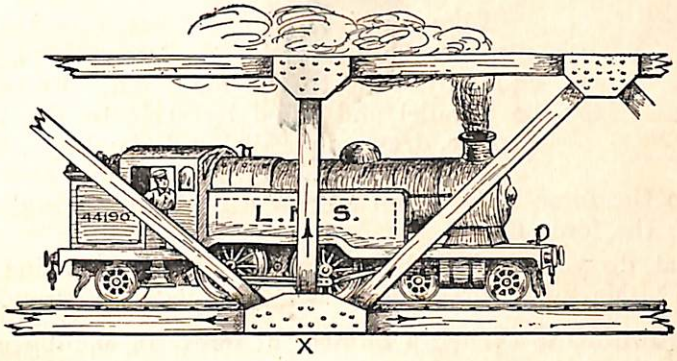
6. A weight of 6 cwts. is suspended from two points 16 ft. apart on a horizontal roof by two ropes 12 ft. and 9 ft. long. Find the tension in each rope.

7. A machine weighs 4 tons and it is supported by two chains attached to the same point in the machine. One chain is fixed to a wall and makes an angle of 30° with the horizontal while the other is fixed to the ceiling and makes an angle of 40° with the horizontal. Find the tension in each chain.

8. The jib of a crane is 40 ft. long, the tie is 30 ft. while the vertical post is 20 ft. If the jib cannot stand a thrust greater than 2 tons weight, what load will break the jib?

THE POLYGON OF FORCES.

Before a girder bridge is built, a problem engineers have to solve is the force acting on each member.



The problem is to find what the forces acting at **X** are, so that the bridge may be soundly constructed.

Experiment.—**To study a number of forces in equilibrium acting at a point.**

Arrange the apparatus as shown in Fig. **1.**

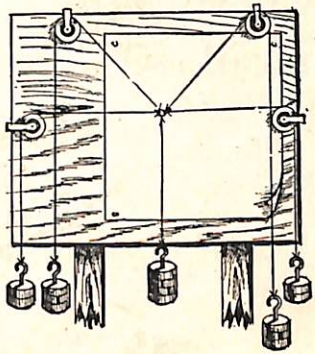


FIG. 1

Trace the positions of the strings very carefully on the paper. Mark the direction of each force with an arrow and note its magnitude. Remove the apparatus and letter the lines as in Fig. 2.

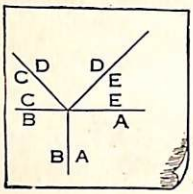


FIG. 2

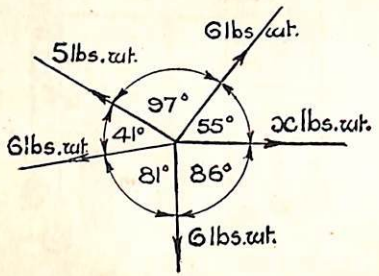
Take a unit of length to represent a suitable number of units of force. Draw **ab** parallel and equal by scale to the force **AB**. From **b**, draw **bc** parallel and equal by scale to the force **BC**. From **c**, draw **cd** parallel and equal by scale to the force **CD**. From **d**, draw **de** parallel and equal by scale to the force **DE**. From **e** draw a line parallel and equal by scale to the force **EA**.

What do you notice about the end of this last line and the point **a**? Mark the direction of each force with an arrow.

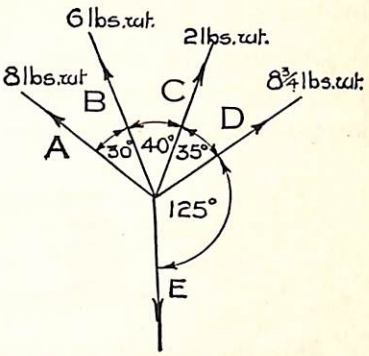
CONCLUSION.—When a number of forces in equilibrium act at a point, the forces may be represented in magnitude and direction by the sides of a .... taken in order.

Questions.

1. Write out and complete the following statement. When any number of forces in equilibrium act at a point, they can be represented in magnitude and direction by .... taken in order. (This is the Polygon of Forces.)
2. A number of forces act at a point as shown. The forces are in equilibrium. Find the unknown force.



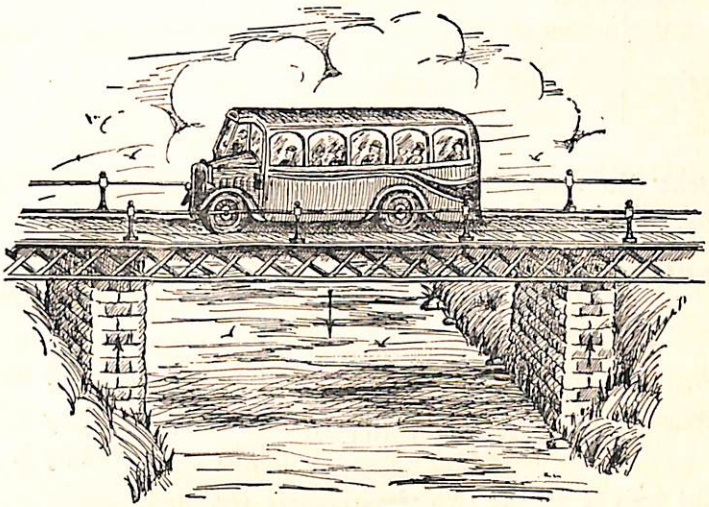
3. (*a*) Five forces, **A**, **B**, **C**, **D** and **E** in equilibrium act at a point as shown in the diagram. Find the magnitude of **E**, the unknown force.



(*b*) Check your result as follows. Find the resultant of **A** and **B**. Let it be R_1. Find the resultant of **C** and **D**. Let it be R_2. Find the resultant of R_1 and R_2. Call it R_3. R_3 must be the .... force of **E**.

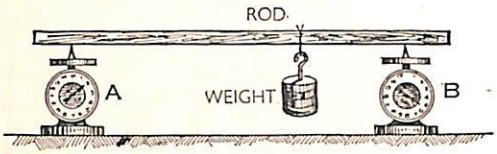
PARALLEL FORCES.

The problem is to find out how much of the weight of the bus is supported by each pier of the bridge.



Experiment.—**To find the weight supported by each pier of a bridge.**

Arrange the apparatus, which represents the bus, the bridge and its piers, as shown below so that half the weight of the rod is supported by each balance.



Put the weight at any point between the two balances. Note the extra reading shown on each balance and also the distance of the weight from each balance. Put the results in a table as shown below.

Extra reading on balance A.	Distance of Weight from balance A.	Extra reading on balance B.	Distance of Weight from balance B.	Sum of extra readings.

Repeat the experiment twice with the weight in different positions.

CONCLUSION.—At 1st position { **weight supported by A =** / **weight supported by B =**

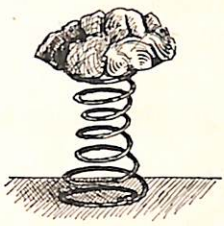
At 2nd position { **weight supported by A =** / **weight supported by B =**

At 3rd position { **weight supported by A =** / **weight supported by B =**

The total weight on the two piers is .... the load.

PARALLEL FORCES (*Continued*).

Here is a stone which weighs 4 lbs. at rest on a spring.

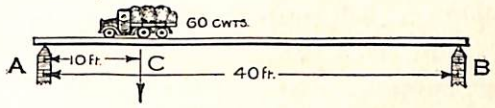


What is pulling the stone? In what direction is it being pulled? Since the stone is at rest, what must the spring be doing to the stone? In what direction must the spring be doing this?

If the pull on the stone were greater than the push of the spring, what would happen to the stone? If the push of the spring were greater than the pull on the stone, what would happen to the stone?

Since the stone is at rest, what is the magnitude and direction of the force exerted by the spring? This force is called the reaction.

To find the weight on each pier of a bridge (by moments).



The diagram represents a bridge 40 ft. long, resting on two piers, **A** and **B**, while at **C**, 10 ft. from **A** is a vehicle weighing 60 cwts.

In what direction is the vehicle being pulled by the earth? Show this in a diagram, using an arrow.

The previous experiment shows that part of the weight of the vehicle is supported by **A** while the rest of the weight is supported by **B**. If R_1 cwts. are supported by **A** and R_2 cwts. are supported by **B**, what do you know about $R_1 + R_2$? What is the reaction at each pier in magnitude and direction? Show this in your diagram, using arrows.

How many forces act on the bridge as a result of the vehicle being on it?

Choose **A** as an imaginary fulcrum. Since the bridge is not turning, although forces are applied to it, the moment clockwise must be .... to the moment anti-clockwise. What is the moment of the force acting at **A**? Calculate the moment due to the weight of the vehicle. Is this moment clockwise or anti-clockwise? Calculate the moment due to the force acting at **B**. Is this moment clockwise or anti-clockwise? Equate these moments and thus find R_2.

What does $R_1 + R_2$ equal? Find R_1.

Check your results by taking **B** as the imaginary fulcrum.

CONCLUSION.—The weight at A = and the weight at B =

Questions.

1. Find the weight on each support of a plank bridge of 8 ft. span, when a man who weighs 12 stones stands on the plank at a point 2 ft. from one support. (Neglect the weight of the plank.)
2. Two men carry a cask which weighs $1\frac{3}{4}$ cwts. The cask hangs from a pole 7 ft. long, each end of the pole resting on a man's shoulder. The point from which the cask hangs is 1 ft. nearer one man than the other. What weight does each man carry? (Neglect the weight of the pole.)

3. A ladder, 28 ft. long, rests horizontally on two pegs, each peg being 3 ft. from the ends. If the ladder weighs 66 lbs. and its centre of gravity is 9 ft. from one end of the ladder, find the weight on each peg.

4. A uniform plank 16 ft. long, rests horizontally on two supports, one support being at the end of the plank while the other is 4 ft. from the end. How much of the weight does each support carry ?

5. Find the weight supported by each pier of a bridge 60 ft. span, if a vehicle weighing 3 tons is in the following position :—(*a*) 5 ft. from one end ; (*b*) 10 ft. from one end ; (*c*) half-way across the bridge. (Neglect the weight of the bridge.)

6. If the bridge itself in the previous question, weighs 40 tons and its centre of gravity is at its mid-point, find the weight carried by each pier when the vehicle is at the given positions.

7. A plank 10 ft. long, is supported at each end. The plank is uniform and weighs 20 lbs. One of the supports **A**, can bear a maximum load of 66 lbs. How far from the other support **B**, can a painter, who weighs 10 stone, go without support **A** collapsing ?

FRICTION.

Experiment.—**To find the force required to make an object just move.**

Arrange the apparatus as shown in Fig. 1.

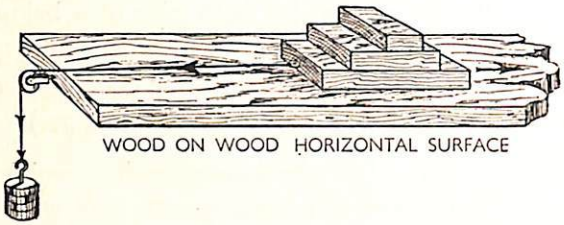


FIG. 1

Add weights to the end of the cord until the blocks just move.

CONCLUSION.—The force required to make the blocks just move = ...

Definition.—**The force which keeps an object from moving is due to the friction between the surfaces.**

Note.—In the previous experiment, when some weights had been added to the cord but not enough to cause the blocks to move, the blocks were being pulled to the left. Since the blocks were not moving, in what direction must the force due to friction have been acting? Friction opposes motion.

Experiment.—**To find if friction depends on the area of the rubbing surfaces.**

Place the blocks as shown in Fig. 2 and again find the force that just makes the blocks move.

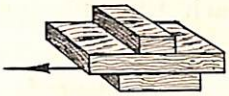


FIG. 2

Repeat the experiment, placing the blocks as in Fig. 3.

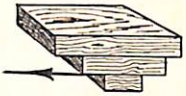


FIG. 3

CONCLUSION.—The friction { **depends** / **does not depend** } **on the area of the rubbing surfaces.**

Experiment.—**To find if friction is the same between different kinds of surfaces.**

Use the same apparatus as in the previous experiment but place the blocks so that a metal covered face is next to the horizontal surface. Find the force required just to move the blocks.

Repeat the experiment with (1) the glass covered face and (2) the linoleum covered face next to the horizontal surface.

CONCLUSION.—The friction { **depends on** / **does not depend** } **on the kind of surfaces in contact.**

Experiment.—**To find if friction depends on the load.**

Arrange the apparatus as in the first experiment on friction. Put a weight on the top of the blocks and find the force required just to move the blocks.

Repeat this twice, each time placing another weight on the blocks.

CONCLUSION.—The friction { **depends** / **does not depend** } **on the load.**

NOTES ON FRICTION.

Friction is the force which must be overcome before one object moves over another. Friction opposes the force applied to the object.

The force necessary to overcome friction depends on the nature of the surfaces in contact. You will slide further on ice (a smooth surface) than on the pavement (a rough surface), *i.e.* the opposing force of friction between your boots and the ice is { greater / less } than the opposing force between your boots and the pavement. If there were no opposing force, *i.e.* no friction, how far would you slide? What is it, then, that stops you when sliding? Can friction be done away with altogether?

In machinery, some of the force developed by the engine, is used in overcoming the friction between moving parts. This force is not being usefully employed and thus engineers try to reduce friction as much as possible by using smooth surfaces, ball bearings and by oiling moving parts. Again, friction causes heat. Heat causes expansion and in machinery, room must be left for this expansion.

Sometimes, however, friction is useful, for example in brakes used to stop movement. What kind of surface should brakes have? Should the brakes have a large or small surface?

The tyres of a motor vehicle are made with a tread (*i.e.* rough) to prevent the vehicle from sliding (*i.e.* skidding). If the road is very slippery, how is the force of friction between the tyres and the road made still greater?

The railway lines and the wheels of the engine are both very smooth and the force of friction between them would seem to be very small. The wheels, then should slip, *i.e.* revolve without moving forward. (At one time it was proposed to make teeth in the rims of the wheels and notches in the rails into which the teeth would fit.) But the friction between the wheels and rails is great because the pressure is great.

When a nail has been driven into a piece of wood, some force is necessary to pull it out. If the nail has rusted, *i.e.* the surface has become rougher, more force is required. What keeps the nail in its place?

Questions.

1. A desk on a level floor is pushed horizontally with a force of (*a*) 10 lbs. weight; (*b*) 20 lbs. weight. In neither case does it move. Why? What must be the magnitude and direction of the force which keeps it from moving?
2. Does friction depend on (*a*) the nature of the surfaces in contact; (*b*) the area of the surfaces in contact; (*c*) the load?
3. Describe an experiment which shows that friction does not depend on the area of the rubbing surfaces.
4. In designing a brake, should the brake pads be large or small? Give a reason for your answer.
5. Name any methods which are used to reduce friction.

Definition.—**Work is done when a force moves an object.**

The amount of work done is measured by multiplying the force employed by the distance the object moves in the direction in which the force acts.

FIG. 1

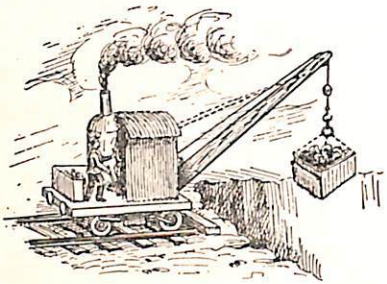


FIG. 2

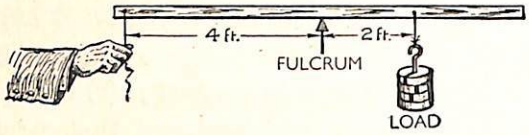
FIG. 3

In Fig. 1, the 100 lb. weight has been lifted a height of 7 ft. How much work has been done?

The crane in Fig. 2 has raised a load of 2 cwts. a height of 10 ft. Calculate the work done.

A 12 stone man, Fig. 3, walks upstairs a height of 30 ft. How much work has he done?

Draw the lever in the following diagram to scale, showing the



load raised 1 ft. above the horizontal. How far has the man's hand moved downwards? How many times is the distance moved by the effort greater than the distance moved by the load? This is called the velocity ratio.

Definition.—**The velocity ratio is the number of times the distance moved by the effort is greater than ....**

The efficiency of a machine

$$= \frac{\text{The useful work done by a machine}}{\text{The work done on the machine}} \times 100.$$

$$= \frac{\text{Load} \times \text{distance load moves}}{\text{Effort} \times \text{distance effort moves}} \times 100.$$

$$= \frac{\text{Load}}{\text{Effort}} \times \frac{\text{distance load moves}}{\text{distance effort moves}} \times 100.$$

$$= \text{Mech. adv.} \div \frac{\text{distance effort moves}}{\text{distance load moves}} \times 100.$$

$$= \frac{\textbf{Mech. adv.}}{\textbf{Velocity ratio}} \times 100.$$

Questions.

1. Calculate the work done in each of the following cases :—
   (*a*) A man lifts 100 lbs. to a height of 7 feet.
   (*b*) A weight of 10 stones is lifted vertically a distance of 6 feet.
   (*c*) A 7 lb. bag of sugar is lowered from a shelf 6 feet above the floor, on to the floor.
   (*d*) A labourer carries ½ cwt. of bricks to the top of a wall 10 feet high. The man himself weighs 10 stones. How much work has he done ? How much useful work has he done ?
   (*e*) A boy who weighs 6 stones, carries his bicycle, which weighs 26 lbs. up a rough slope a distance of 50 feet. He is then 10 feet above the bottom of the slope. How much work has he done ?

2. Define (*a*) mechanical advantage ; (*b*) velocity ratio ; (*c*) efficiency.

THE PULLEY.

The sketch shows a method of lifting a load. A pulley is being used

Experiment.—**To study the pulley.**

1st Part.—Arrange the apparatus as shown in Fig. 1. Pull the cord at **B.** In what direction does the load move ? In what direction does the effort move ?

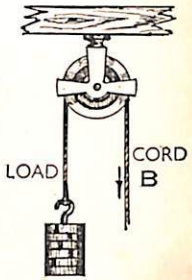
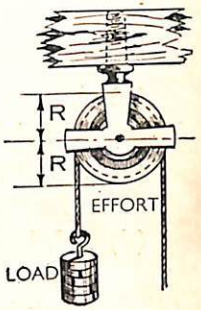


FIG. 1

CONCLUSION.—A pulley can be used to ..... the direction of a force.



2nd Part. — Measure the radius of the pulley.

Suppose the load weighs 10 lbs. What is the moment anti-clockwise ? If the effort just balances the load, what is the moment clockwise ? What should be the effort ?

CONCLUSION.—The mechanical advantage should be .....

3rd Part.—Put any load on to one end of the cord and find what force is actually required just to raise the load. Put the results in a table as shown.

Useful load	Effort	Mech. adv. = $\frac{\text{Load}}{\text{Effort}}$	Efficiency = $\frac{\text{Mech. adv.}}{\text{Vel. ratio}} \times 100$
·25	·27	·926	
·50	·535	·932	
1·000	1·075	·930	

Repeat the experiment twice, each time increasing the load by an equal amount. Is the load or the effort the greater? When the load is being raised, does friction take place? Where? Why is there a difference between the load and the effort?

CONCLUSION.—The effort is .... than the load because .... has to be overcome. Therefore the mechanical advantage is .... than .....

4th Part.—Put a ruler vertically beside the load and another vertically beside the effort. Measure the distance moved by the load and by the effort. Complete the table.

CONCLUSION.—The velocity ratio of the pulley is .....

Questions.

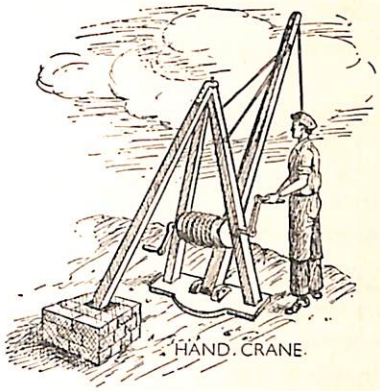
1. To raise a sack of flour weighing 120 lbs. using a pulley, a man requires to use an effort of 160 lbs. weight. (*a*) Where has the extra force gone? (*b*) What benefit is there in using the pulley?

(Refer to question 1 (*d*), page 59). (*c*) If there were no friction, what would be the mechanical advantage? (*d*) What is the velocity ratio? (*e*) What do you notice about what the mechanical advantage should be and the velocity ratio? (*f*) Find what the mechanical advantage really is. (*g*) What is the efficiency of the pulley?

2. The efficiency of a pulley is 80 per cent. What effort is required to raise a load of 100 lbs.?

THE WHEEL AND AXLE.

The sketches below show examples of a machine called the wheel and axle.



Experiment.—**To study the wheel and axle.**

1st Part.—Measure the radius of the wheel and of the axle Fig. 1. How many times is the radius of the wheel greater than the radius of the axle?

Suppose the load is 10 lbs. What is the moment clockwise? If the effort just balances the load, what should be the effort?

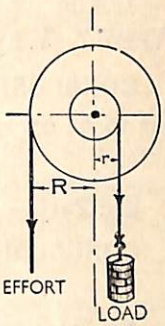


FIG. 1

CONCLUSION.—The mech. adv. should be .... and the radius of the wheel is .... times the radius of the axle.

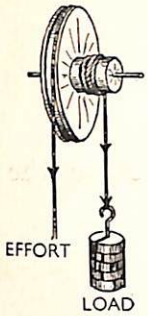


FIG. 2

2nd Part.—Arrange the apparatus as shown in Fig. 2. Put any load on the axle cord and find what force is actually required just to raise the load. Put the results in a table as shown below.

Useful load	Effort	Mech. adv. = $\frac{\text{Useful load}}{\text{Effort}}$	Efficiency = $\frac{\text{Mech. adv.}}{\text{Vel. ratio}} \times 100$

Repeat the experiment twice, each time increasing the load by an equal amount.

Is the load .... times the effort? Does friction take place? Where? Why is the load not .... times the effort?

CONCLUSION.—The load is not .... times the effort because .... has to be overcome. Therefore the mech. adv. is .... than .....

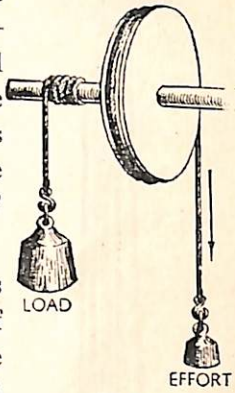
3rd Part.—Find the velocity ratio as in the previous experiment.

CONCLUSION.—The velocity ratio = ...

4th Part.—If the wheel makes one complete turn, how much cord is pulled down? What distance does this cause the load to rise? Complete the above table.

CONCLUSION.—The velocity ratio = ...

Questions.



1. In a wheel and axle, the radius of the wheel is 6 inches and the radius of the axle is 2 inches :— (*a*) Find what the mechanical advantage should be ; (*b*) find the velocity ratio. (*c*) To raise a load of 60 lbs., an effort of 25 lbs. weight is actually required. What effort should be needed ? Where has the extra force gone ? (*d*) Calculate the efficiency.

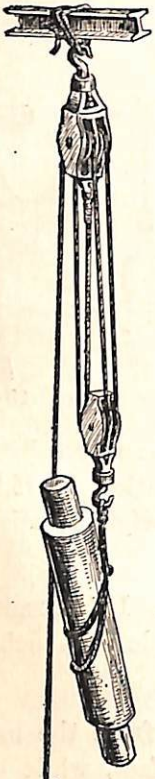
2. In the windlass shown on page 63, the radius of the drum is 6 inches while the length of the handle is $2\frac{1}{2}$ feet :—(*a*) What should be the mechanical advantage ? (*b*) What effort should raise a load of 60 lbs. ? (*c*) What load should be raised by an effort of 10 lbs. weight ? (*d*) Find the velocity ratio. (*e*) If the man actually requires to exert a force of 12 lbs. weight to raise a load of 50 lbs., calculate the efficiency.

3. The efficiency of a wheel and axle is 75 per cent. If the radius of the wheel is $1\frac{1}{2}$ feet and the radius of the axle is 6 inches, what effort is required to raise a load of 90 lbs. ?

4. In the capstan shown on page 63, the distance from the mid-point of the capstan to the man's hands is 6 feet, while the part of the capstan where the rope is, has a radius of 9 inches. What should be the pull on the rope if the man exerts a force of 100 lbs. weight ?

5. In the crane on page 63, the mechanical advantage of the wheel and axle part should be 4. If the radius of the drum is 6 inches, what should be the length of the handle ?

THE BLOCK AND TACKLE.



Another machine used in lifting weights is shown

This machine is called the "**block and tackle**" and this one has two sheaves in each block.

Expt.—**To study the block and tackle.**

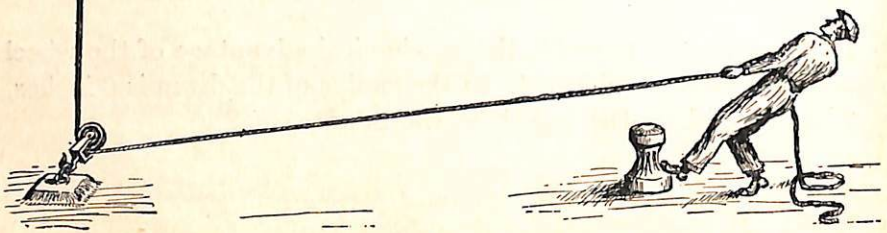
1st Part.—Measure the velocity ratio in the usual way.

CONCLUSION.—The velocity ratio = ...

2nd Part.—How many cords are used to raise the lower block? If the load is raised 1 foot, how far is the lower block raised? How many parts of the cord hold up the lower block? How much has each of these parts been shortened? How much cord has been pulled down at P? How far has the effort been lowered?

CONCLUSION.—The velocity ratio = ...

3rd Part.—If a load of 12 lbs. has been raised 1 foot, how much work has been done? How far has the effort been lowered? What should be the effort?



CONCLUSION.—The mech. adv. should be .... and the number of parts of the cord which support the lower block is.....

4th Part.—Where does friction take place in this machine? When the useful load is being raised, what else must be raised? Therefore the mech. adv. will be ..... than ..... With no load on the lower block find what effort is required just to raise the block. What is the useful load?

Put the results in a table as shown below.

Useful load	Effort	Mech. adv. = $\frac{\text{Useful load}}{\text{Effort}}$	Efficiency = $\frac{\text{Mech. adv.}}{\text{Vel. ratio}} \times 100$

Put a load on the lower block and again find the effort required just to raise it. Repeat this twice, each time increasing the load by an equal amount. Complete the above table. With no useful load what does the effort used do? For every additional load how much has the effort to be increased? If the machine were frictionless how much would the effort need to be increased each time? As the load is increased what do you notice about the mech. adv.? This is because the effort used in doing useless work, *e.g.* in raising the block, becomes of $\frac{\text{more}}{\text{less}}$ importance as the total load increases.

CONCLUSION.—The load is not .... times the effort because .... has to be overcome and also because the lower block has to be raised.

The mech. adv. becomes .... as the load is increased.

Questions.

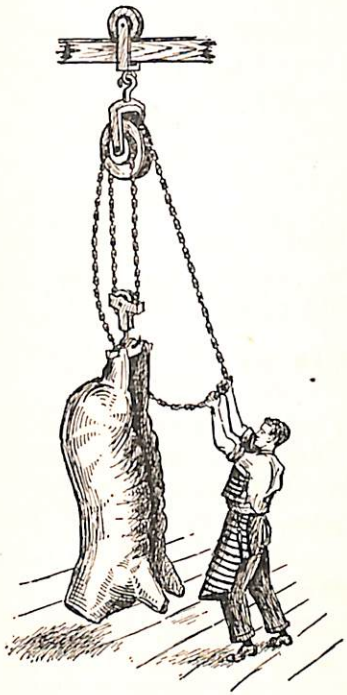
1. A block and tackle has two sheaves in each block :—(*a*) What is the velocity ratio? (*b*) What should be the mechanical advantage? Will it be more or less than this? Give reasons for your answer. (*c*) In such a machine, a load of 240 lbs. is raised by an effort of 80 lbs. weight. Find the mechanical advantage and the efficiency.

2. (*a*) In a similar block and tackle, the efficiency for a load of 300 lbs. is 75 per cent. Find the effort required.
   (*b*) 25 per cent. of the effort is "wasted." Explain this.

3. A block and tackle has three sheaves in each block :—(*a*) When the load is raised one foot, how much has each part of the rope which holds up the lower block been shortened? How far has the effort been lowered? What is the velocity ratio? (*b*) What should be the mechanical advantage? Will it be more or less than this? Give reasons for your answer. (*d*) With such a machine, a load of 480 lbs. is raised with an effort of 100 lbs. weight. Find the mechanical advantage and the efficiency.

4. Draw a diagram of a block and tackle in which the velocity ratio is 8. If the efficiency for a load of 240 lbs. is 60 per cent., find the effort required.

THE WESTON DIFFERENTIAL PULLEY.



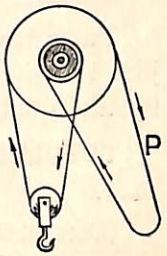
This machine, shown on left, is in common use for hoisting loads.

Experiment.—**To study the Weston differential pulley.**

1st Part.—Examine the two pulleys in the upper block. Do they rotate together? Are they the same size? What do you notice about the links of the chain, and the upper pulleys? Will this increase or decrease the friction? Will this increase or decrease the mech. adv. of the machine? Put a load on, raise it and let go the chain. Does the load run down? Why?

CONCLUSION.—The mech. adv. of this machine is .... by the .... between the chain and the upper pulleys, but it is often convenient to be able to release the chain without the load travelling downwards.

2nd Part.—Measure the radius of each of the upper pulleys. What happens to both of these pulleys when the chain is pulled down at P? If the larger pulley makes one turn, how much chain has been pulled down? How much does this shorten the chain passing under the lower pulley? While the larger pulley has been making one turn, how many turns does the smaller upper pulley make?



When this pulley does turn does it shorten or lengthen the chain under the lower pulley? How much does it shorten or lengthen this chain? What is the total amount that the chain under the lower pulley is shortened for one turn of the larger, upper pulley? How much does the lower pulley rise?

CONCLUSION.—The velocity ratio = ...

3rd Part.—If a load of .... lbs. has been raised one foot, how much work has been done? To raise the load one foot, how far has the effort been lowered? What should be the effort?

CONCLUSION.—The mech. adv. should be .....

4th Part.—With no load on the lower block, find what effort is required just to raise the lower block. What is the useful load?

Put the results in a table as shown below.

Useful load	Effort	Mech. adv. = $\frac{\text{Useful load}}{\text{Effort}}$	Efficiency = $\frac{\text{Mech. adv.}}{\text{Vel. ratio}} \times 100$

Put a load on the lower block and again find the effort required just to raise it. Repeat this twice, each time increasing the load by an equal amount. Complete the table.

CONCLUSION.—The mechanical advantage is not .... because .....

(Complete the above statement, giving two reasons.)

NOTES ON WESTON DIFFERENTIAL PULLEY.

When heavy loads are being raised, care must be taken that accidents do not occur through the load running down when the effort is removed. As we have seen in the experiment with this machine, the load does not run down.

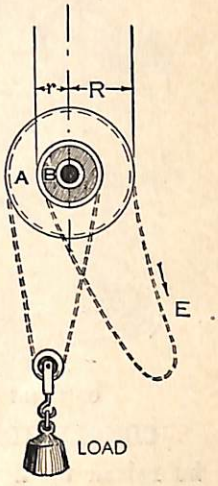
Suppose the efficiency of a machine is less than 50 per cent., *e.g.* 30 per cent. If the effort of 10 lbs. weight has been lowered 10 feet, how much work had been done? How much of this work has actually raised the load? What has the rest of the work done?

If the load returns to its first position, *i.e.* it runs down, it could do only 30 ft. lbs. of work. But 70 ft. lbs. are needed to overcome friction. The load, then, cannot run down. (Actually, when the effort is removed, the pressure is reduced, thus reducing the friction. Thus, a little less than 70 ft. lbs. of work are required.)

If the efficiency of a machine is less than 50 per cent. the load should not run down.

Questions.

1. In a Weston Differential Pulley, the radius of the larger pulley is R, while that of the smaller pulley is r. The velocity ratio is $\frac{2R}{R-r}$.



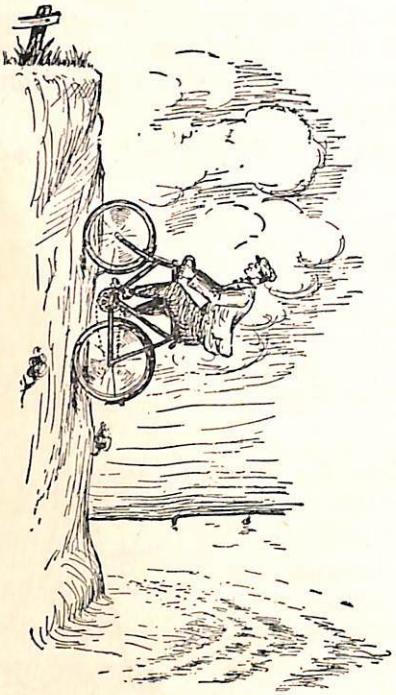
If **A** makes one complete turn, how far does the effort move? How much does this shorten the chain passing under the lower pulley?

When **A** turns once, **B** turns once also and ..... the chain under the lower pulley. How much does it do this? What is the total amount that the chain under the lower pulley is shortened for one turn of **A**?

Since the chain passes round the lower pulley, how much does that pulley rise? What is the velocity ratio?

2. In a Weston Differential Pulley, the radius of the larger pulley is 6 inches, while the radius of the smaller is $5\frac{1}{2}$ inches. Find the velocity ratio :—(*a*) by the formula above ; (*b*) as in question 1. (*c*) If the efficiency is 40 per cent., what load can be raised by an effort of 100 lbs. weight ?

THE INCLINED PLANE.



CAN THIS BE DONE ?

Will the cyclist be able to exert enough force to reach the hill top this way ?

CONCLUSION.—A load which cannot be raised vertically may be raised up a slope.

Definition.—**An inclined plane is a rigid, flat surface which makes an angle with the horizon.**

Experiment.—**To study the inclined plane.**

1st Part.—In Fig. 1, if the load is acted on by the effort, **E** which acts parallel to the plane, what work is done when the load is moved from **A** to **B**?

If the same load, **L** is lifted vertically from **C** to **B**, what work is done?

The work done in lifting the load vertically .... to the work done in lifting it up the plane. What, then, is $\frac{L}{E}$?

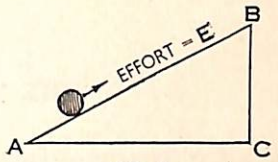


FIG. 1

CONCLUSION.—The mechanical advantage = ...

2nd Part.—When the load is being raised up the plane, does friction take part? Where? The mechanical advantage will thus be $\left\{\begin{matrix}\text{more}\\\text{less}\end{matrix}\right.$ than .... because part of the effort is required to .....

Arrange the apparatus as in Fig. 2, having first weighed the roller. Adjust the cord so that it is parallel to the plane. Find what effort is just sufficient (1) to keep the roller from rolling down the plane and (2) to cause the roller just to move up the plane. Find the average effort. Put the results in a table as shown below :—

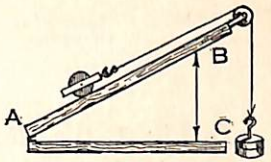


FIG 2.

Load	Average effort	Mech. adv. $= \frac{L}{E}$	Length of plane	Height of plane	$\frac{\text{Length}}{\text{Height}}$

Take any point **B** near the upper end of the plane and measure **AB** and **BC**, where **BC** is vertical. Complete the above table.

Repeat the experiment twice, altering the load and the slope of the plane each time.

CONCLUSION.—The mechanical advantage .... $\frac{\text{length of plane}}{\text{height of plane}}$.

THE INCLINED PLANE (*continued*).

Experiment.—**To study the inclined plane where the effort acts parallel to the base of the plane.**

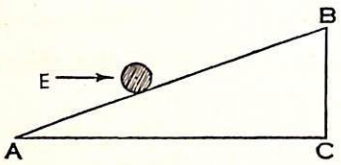


FIG. 1

In Fig. 1, the effort, **E** acts on the load parallel to the base of the plane. What work is done when the load is moved from **A** to **B**?

If the same load, **L** is lifted vertically from **C** to **B**, what work is done? The work done in lifting the load vertically .... to the work done in lifting the load up the plane. What, then, is $\frac{\mathbf{L}}{\mathbf{E}}$?

CONCLUSION.—The mechanical advantage = ...

2nd Part.—The mechanical advantage will be less than this because .....

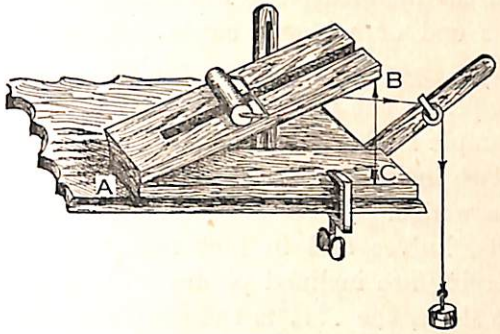


FIG. 2

Arrange the apparatus as in Fig. 2, having first weighed the roller. Adjust the cord so that it is parallel to the base of the plane. Find what effort is just sufficient (1) to keep the roller from rolling down the plane and (2) to cause the roller just to move up the plane. Find the average effort. Put the results in a table as shown below :—

Load	Average effort	Mech. adv. $= \frac{L}{E}$	Length of plane	Height of plane	$\frac{\text{Length}}{\text{Height}}$

Take any point **B** near the upper end of the plane and measure **AC** and **CB** where **CB** is vertical. Complete the above table.

Repeat the experiment twice, altering the load and the slope of the plane each time.

CONCLUSION.—The mechanical advantage .... $\frac{\text{base of plane}}{\text{height of plane}}$

NOTES ON THE INCLINED PLANE.

Examples of the inclined plane are common in everyday life.

To raise one end of a heavy cupboard, sometimes a piece of wood shaped thus, , is driven under it. Instead of pulling the load up the plane, the plane is moved under the load.

Another example is the wood chisel.

Sometimes two inclined planes are joined thus, which is the usual shape of a wedge.

Driving nails, knives and in fact many instruments used for cutting and piercing are inclined planes and, as we have seen, the more gentle the slope, the .... is the mechanical advantage.

Miners use a " self-acting " incline in pits whenever the coal has to be taken from a higher to a lower level. There are really two inclined planes, side by side. A wire rope is attached to the full (or descending) tubs, passes round a pulley controlled by a brake and is then linked to the empty (or ascending) tubs. The gradient is such that the weight of the full tubs going down one incline is sufficient to pull the empty tubs up the other.

Questions.

1. What is an inclined plane ?
2. What is the mechanical advantage of an inclined plane in which the effort is applied :—(*a*) parallel to the plane ; (*b*) horizontally ? (Neglect friction.)
3. (*a*) An inclined plane is 6 ft. high and 60 ft. long. What force, parallel to the plane, is required just to support a load of 400 lbs. ?

   (*b*) If the plane is the same length but 12 ft. high, what force would be required ?

(*c*) Write out and complete the following statement. The more gentle the incline, the .... the mechanical advantage.

(*d*) Roads and railways zigzag their way across mountains. Why ?

(*e*) In cycling up a steep hill, the cyclist frequently crosses from side to side of the road. Why ?

4. A road rises 1 ft. in 4 ft. of road. What force, parallel to the road, is required to keep a vehicle weighing 1 ton, stationary ? (Neglect friction.)

5. The base of an inclined plane is 50 ft. long and its height is 5 ft. :—(*a*) What horizontal force is needed to keep a load of 200 lbs. at rest on the plane ? (*b*) What load should be supported by an effort of 5 lbs. weight acting horizontally ?

6. An inclined plane is 5 ft. long and 3 ft. high. Find the length of the base. Is the mechanical advantage greater when the effort is applied :—(*a*) parallel to the plane or (*b*) horizontally ?

7. A vehicle weighing 1 ton can be kept stationary on an incline by an effort of 1 cwt. applied parallel to the plane. If the incline is 40 ft. long, what is its height ?

THE SCREW.

Figure 1 shows a familiar method of joining two pieces of wood.

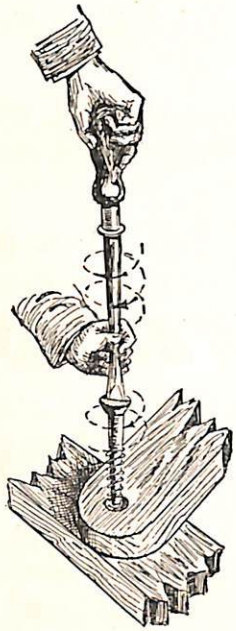
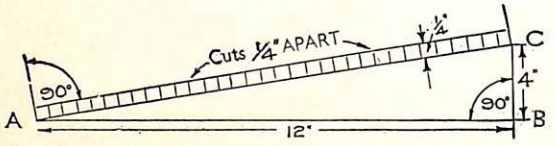


FIG. 1

Experiment.—**To study the screw.**

1st Part.—Cut out of very thin sheet metal, a piece as shown below.



Bend the narrow strip at right angles to the triangular part. Put **AB** horizontal and **BC** vertical. If the narrow strip were rigid, what would it form? Cut the narrow strip as shown. Place **BC** flat against a cylinder of about 1 inch diameter and wrap the metal round the cylinder so that **AB** is even with the base of the cylinder. If there were no cuts in the narrow strip, it would form the .... of a screw.

CONCLUSION.—The thread of a screw is .....

2nd Part.—Mark where point **A** touches the base of the triangular part. Unwind the metal and draw a line **DE**, perpendicular to the base, from this point to **AC**. Re-wind the metal round the cylinder. If this screw makes one turn, how far does the screw move? This distance is called the pitch of the screw. This distance is also the .... of the inclined plane **AE**. What part of the screw is the base **AD**?

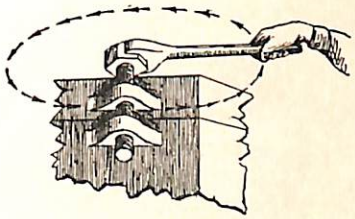


FIG. 2

If the screw is turned with a spanner as in Fig. 2, the effort is applied parallel to the .... of the inclined plane. From the experiments on the inclined plane, what is the mechanical advantage of an inclined plane in which the effort is applied in that direction?

CONCLUSION.—The mechanical advantage of a screw = ...
(Use the terms which apply to a screw.)

3rd Part.—Does friction take place when a screw is being used ? Where ?

CONCLUSION.—The mechanical advantage will be .... than .....

Some interesting examples of screws are shown below.

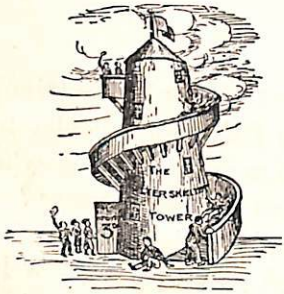


FIG. 3

FIG. 4

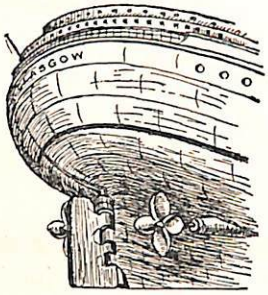
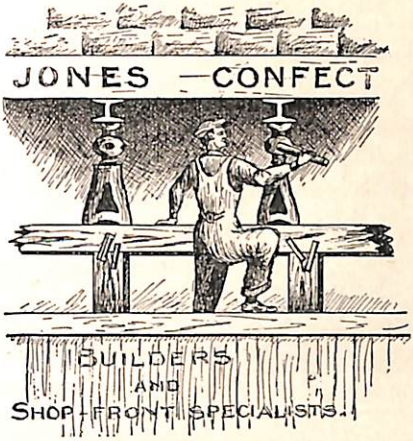


FIG 5.

Fig. 3 shows an amusement park use of the screw. **In Fig. 4, the propeller is a pulling screw while we have twin screws in Fig. 5.**

THE SCREW JACK.

The screw jack is commonly used in garages and by builders. Using a number of screw jacks, a whole roof weighing many tons has been lifted to allow a storey to be added to the building.



Experiment.—**To study the screw jack.**

1st Part.—Examine a screw jack. What happens to the load when the lever arm is turned clockwise? What happens to the load when it is turned anti-clockwise?

What is the length of the arm of the jack? When the arm makes one complete turn, what figure is described by the operator's hand? What distance does the effort move?

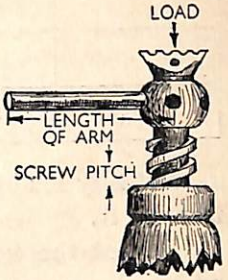


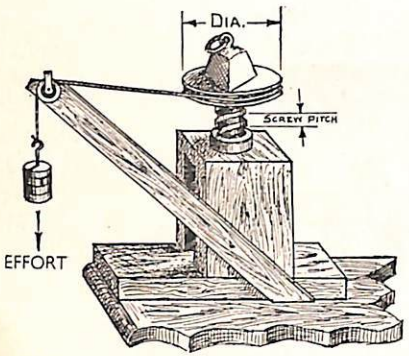
FIG. 1

Measure the pitch of the screw. If the jack arm makes one complete turn, how far has the load been raised?

CONCLUSION.—The velocity ratio = ...

2nd Part.—If a load of .... lbs. has been raised .... foot, how much work has been done? To raise the load that distance, how far has the effort moved? What should be the effort?

CONCLUSION.—The mechanical advantage should be .....



3rd Part.—Construct a model jack (using a large bolt and nut) and arrange it as shown in Fig. 2. With no load on the turntable, find what effort is required just to raise the turntable. What is the useful load? Put the results in a table as shown below.

Useful load	Effort	Mech. adv. $= \frac{\text{Useful load}}{\text{Effort}}$	Efficiency $= \frac{\text{Mech. adv.}}{\text{Vel. ratio}} \times 100$

Put any load on the jack and again find the effort required just to raise it.

Repeat the experiment twice, each time increasing the load by an equal amount. Complete the table.

CONCLUSION.—The mechanical advantage is not .... because .....

(Complete the above statement, giving two reasons.)

Questions.

1. (*a*) What is the thread of a screw?
   (*b*) What is meant by the pitch of a screw?
   (*c*) What is the mechanical advantage of a screw, if the radius is r inches and the pitch is p inches?

   (*d*) If the pitch of the screw is made less, what happens to the mechanical advantage? The reason is that when the pitch is made less, the inclined plane has a more .... slope.

2. The pitch of a screw jack is P inches and the arm is R inches long. If the effort is applied at the end of the arm, find :—(*a*) the velocity ratio. (*b*) If the jack worked without friction, what would be the mechanical advantage?

3. (*a*) If the length of the arm of a screw jack is increased, what will happen to the mechanical advantage?
   (*b*) In using a screw driver, what is the arm?

4. (*a*) In a screw jack, the pitch is $\frac{1}{2}$ inch and the arm is 14 inches long. Find the velocity ratio and what the mechanical advantage should be. ($\pi = \frac{22}{7}$.)
   (*b*) Using the jack, the effort applied at the end of the arm equals 10 lbs. weight and a weight of 880 lbs. can just be raised. Find the mechanical advantage and the efficiency.

5. If there are two threads to an inch on a screw jack and the arm is 28 inches long, find the load raised when an effort of 5 lbs. weight is applied at the end of the arm, if the efficiency is 75 per cent.

THE COMPOUND BELL CRANK LEVER.

The sketches below illustrate the brake mechanism on a railway waggon.

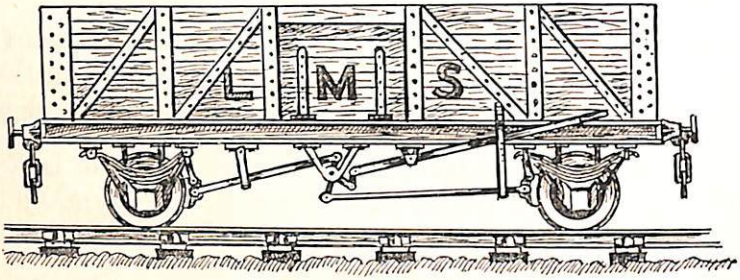


FIG. 1

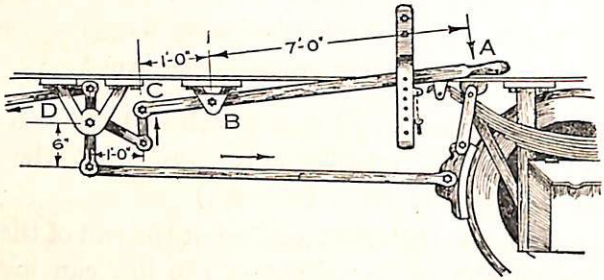


FIG. 2

The mechanism consists of a straight lever and a bell crank lever. Two or more levers linked together form a compound lever.

To examine a compound bell crank lever.

1st Part.—When a force is applied as shown at **A**, at what point does the straight lever turn? If the force applied is equal to a weight of 100 lbs., what is the force acting at **C**? In what direction does this force act? What force is applied to the longer arm of the

bell crank lever? When this force is applied at that point, where does the bell crank lever turn? What does the bell crank lever do to the direction of this force? In what directions are forces now acting? What happens to the brake blocks?

2nd Part.—In a simple bell crank lever, if a force acts as in Fig. 4, what force would be required to be applied to the shorter arm, as shown, to restore equilibrium?

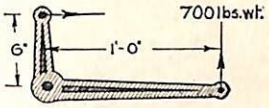


FIG. 4

3rd Part.—If the bell crank lever has two equal short arms as in Fig. 5, what is the magnitude of each of the two forces required to restore equilibrium, if these two forces are equal?

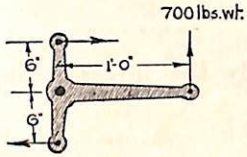


FIG. 5

4th Part.—In operating the brakes on the truck, what is the force applied by each short arm of the bell crank lever if each short arm is 6 inches long?

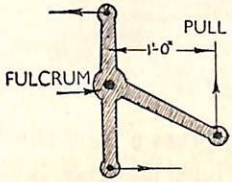
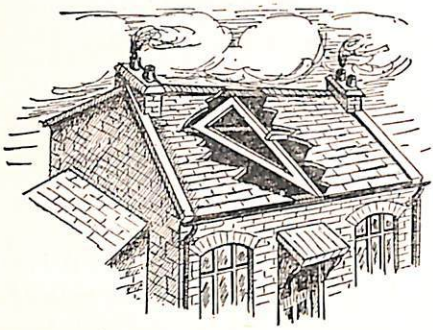


FIG. 6

THE ROOF TRUSS.

The structure shown where the roof has been removed, is a roof truss. The builder must calculate the load on each roof truss of a building and construct the truss so that each section of the roof is safely carried. Also, if the truss is made too strong there is waste of material.



Experiment.—**To study the forces acting in each member of a triangular roof truss.**

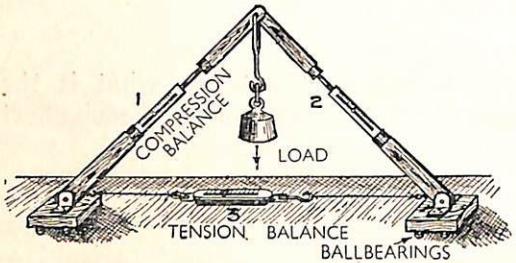


FIG. 1

Use a model roof truss as shown in Fig. 1. Load the truss as shown. What does the load do to each sloping member? What does it do to the horizontal member?

If a force tends to compress a bar, the bar is called a strut. If a force tends to stretch a bar, the bar is called a tie. The sloping members, therefore are .... while the horizontal member is a ....

Each member resists the tension or the compression as seen in Fig. 2 and Fig. 3.

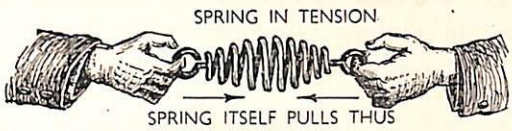


FIG. 2

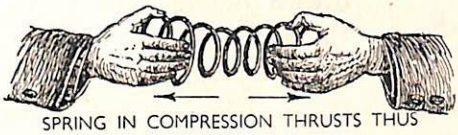


FIG. 3

Make a diagram of the loaded truss and show by an arrow at each end of each member of the truss, the directions the forces in the members must be acting.

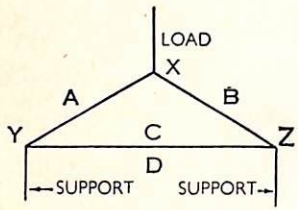
Take the reading on each balance. Add an extra load and again take the readings. Put the results in a table as shown below.

Extra load	Extra reading on balance 1	Extra reading on balance 2	Extra reading on balance 3

CONCLUSION.—The force in each sloping member = ...
(This force is a thrust.) The force in the horizontal member = ...
(This force is a pull.)

THE ROOF TRUSS.

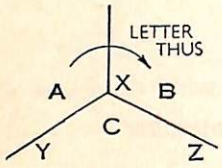
To find graphically the forces in the members of a triangular roof truss.



Using a suitable scale, draw a roof truss loaded as in the previous experiment. Letter it **XYZ.** At **X**, show by an arrow drawn outside the truss, the direction of the force due to the load. At **Y** and **Z** show by arrows, also drawn outside the truss, whether the truss supports (the walls) are in compression or tension.

(Note.—The lines representing these forces and the lines representing the truss members, divide the paper into spaces. Letter these **A, B, C** and **D.** This is Bow's notation.)

1st Part.—Joint at X. How many forces are acting at **X**? Since **X** is in equilibrium, how can these forces be represented? Draw the figure which represents these forces.

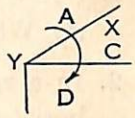


(Note.—**ab** is the force between **A** and **B.**
bc ,, ,, ,, ,, **B** and **C.**
ca ,, ,, ,, ,, **C** and **A.**

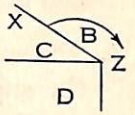
In drawing the figure, the forces should be taken in order, the same way round, *e.g.* **ab**, **bc** and **ca** in the direction shown by the arrow.)

Using a suitable scale, draw a line **ab** vertically downwards to represent the load. Mark its direction with an arrow. From **b**, draw a line parallel to **XZ** and from **a**, draw a line parallel to **XY**. Let these lines meet in **c**. In the figure put arrows to show what must be the directions of the other two forces. Measure the lengths of **ac** and **bc**. What forces do these lines represent? Compare with experimental results.

2nd Part.—Joint at Y. Name the forces at this joint which are now known in (1) magnitude and (2) direction. Find the unknown forces in magnitude and direction. Forces to be taken in the direction shown by the arrow. Compare with experimental results.



3rd Part.—Joint at Z. How many forces act at **Z**? Name those which are now known in (1) magnitude and (2) direction. Find the unknown forces in magnitude at direction. Forces to be taken in the direction shown by the arrow. Compare with experimental results.



4th Part.—Forces of truss supports. Neglecting the weight of the truss itself, what would you expect the upthrust to be at each support? What actually is the upthrust?

5th Part.—Could the figures obtained in the 2nd and 3rd parts be combined to form the figure obtained in the 1st part?

CONCLUSION.—The force in each sloping member = ... and these members are in {**compression, tension** *i.e.* **they are** {**struts. ties.**

The force in the horizontal member = ... and it is in {**compression, tension** *i.e.* **it is a** {**strut. tie.**

Questions.

1. (*a*) If forces tend to compress a bar, what is the bar called ?
   (*b*) What is a tie ?

2. In a roof truss, each sloping member is 14 ft. long, while the horizontal member is 20 ft. Find graphically the forces acting in each member, when a load of 300 lbs. is carried at the apex.

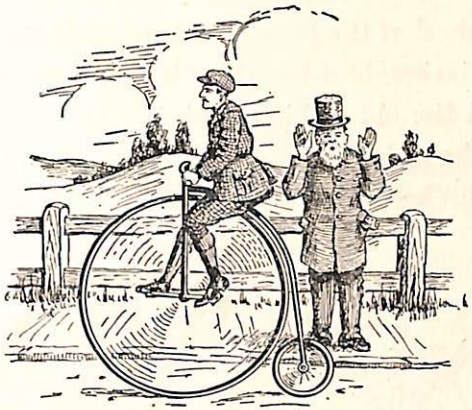
3. In a roof truss, the sloping members are 21 ft. and 18 ft. respectively, while the horizontal member is 27 ft. A load of 400 lbs. is carried at the apex. Find the forces in the members.

4. The span of a roof truss is 30 ft. while the truss rises 20 ft. above the supports. Find the forces in the members when a load of 560 lbs. is carried at the apex.

5. (*a*) A roof truss has a span of 30 ft. and the angle of the roof is 45°. If the load carried at the apex is 5 tons, what are the forces in the members ?
   (*b*) What weight does each side wall carry, if there are 20 such trusses on it ?
   (*c*) If good timber can take a safe load of 450 lbs. per sq. inch, what should be the area of the cross section of each member ? (Ans. to nearest whole number.)

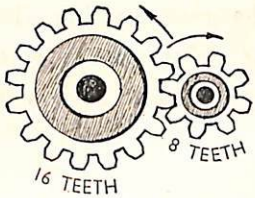
THE BICYCLE.

The sketch shows an old fashioned bicycle called the "penny farthing."



Experiment.—**To find what the gear number of a bicycle means.**

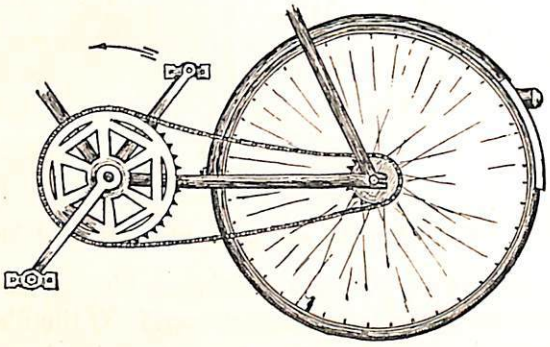
When the pedals of this old fashioned bicycle make one turn, how many times does the larger wheel turn? If the diameter of this wheel is seventy inches, how far does the bicycle travel for one turn of the pedals?



Sketch number 2 shows two toothed wheels in mesh. If the larger wheel turns once, how many turns does the smaller wheel make?

In a bicycle, how are wheels like these coupled? If the pedals turn once, how often does the larger wheel turn? If there are 45 teeth in the larger wheel and 18 in the smaller, how many turns does the smaller make if the larger turns once? How often will this cause the back wheel of the bicycle to turn? If the diameter of the back wheel is 28 inches, how far will this cause the bicycle to travel? This bicycle and the old fashioned bicycle travel an .... distance for one turn of the pedals.

The gear number of this bicycle is 70.



CONCLUSION.—If the gear number of a bicycle is X, we mean that for every turn of the pedals, the bicycle travels as far as a gearless bicycle with the large wheel X inches in diameter.

Questions.

1. What is meant by saying that the gear number of a bicycle is 72 ?

2. The crank wheel of a bicycle has $2\frac{1}{2}$ times as many teeth as the sprocket wheel. If the diameter of the back wheel is 28 inches, find the gear number.

3. (*a*) The gear number of one bicycle is 70 while that of another bicycle is 35. How far does each bicycle travel for one turn of the pedals ?

   (*b*) Which is the easier cycle to ride ? Why ?

4. (*a*) If a road is level, what force must a cyclist overcome before he moves ?

   (*b*) Would a heavier cyclist need to exert more or less force before he moves ? Give a reason for your answer.

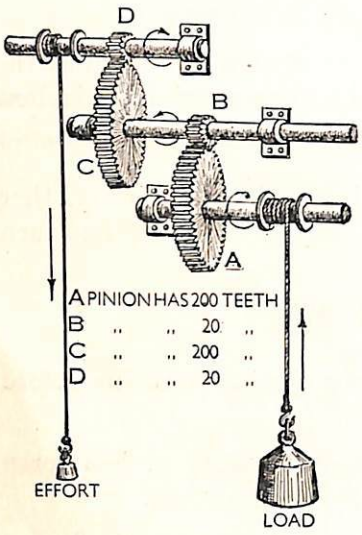
   (*c*) If a road is steep, what other force must be overcome ?

   (*d*) When a bicycle has a three-speed gear, when is the low gear used ?

   (*e*) What is the purpose of the ball bearings ? Why are some parts oiled ?

GEARING.

To study gearing.



Here are shown toothed wheels mounted on axles so that when the axles revolve, so do the wheels.

If wheel **A** turns once, how often does wheel **B** turn? How often does **C** turn? How often does **D** turn?

If the load is on the axle of **A** and the effort is applied at the axle of **D**, how far does the effort move when the load is raised 1 ft.? What is the velocity ratio?

If the effort is equal to 100 lbs. weight, what should be the load? What should be the mechanical advantage? What does the effort move as well as the load itself? Give two reasons why the mechanical advantage cannot be what it should.

CONCLUSION.—By using toothed wheels, a load greater than the effort can be raised but the load moves more {**quickly** / **slowly**} **than the effort.**

2nd Part.—If the effort is applied at the axle of **A** and the load is on the axle of **D**, how far does the load move when the effort moves 1 ft.? What is the velocity ratio? What should be the mechanical advantage?

CONCLUSION.—Toothed wheels can also be used to raise a load less than the effort but in this case, the load moves more {**quickly** / **slowly**} **than the effort.**

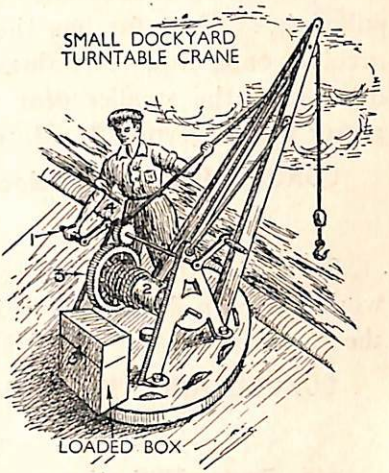
GEARING. THE CRANE.

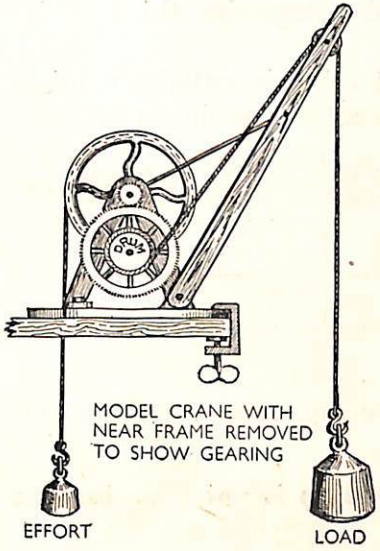
The mechanism which enables heavy loads to be lifted using a crane, is shown here.

The names and dimensions of the crane parts are as follows :—

1. Power pulley. (3 ft. in dia.)
2. The drum. (1 ft. in dia.)
3. Large gear wheel. (200 teeth.)
4. Small gear wheel. (20 teeth.)

When the power pulley is turned, the small gear wheel turns also. This causes the large gear wheel to turn, the drum turns and the rope is wound on or off the drum, thus causing the load to be raised or lowered.





Experiment.—**To study the gearing of a crane.**

1st Part.—Using a model crane (in which the effort of the man is replaced by a weight), find the velocity ratio in the usual way.

CONCLUSION.—The velocity ratio = ...

2nd Part.—(Note.—In measuring the diameters, find the diameter of the drum or pulley and the diameter plus the rope and take the average.).

If the drum makes one complete turn, how much rope has been pulled in? How far has the load been raised? When the drum revolves once, how often does the larger gear wheel revolve? How often does the smaller gear wheel revolve? How often does the power pulley revolve? How far does the effort travel?

CONCLUSION.—The velocity ratio = ...

3rd Part.—If a load of .... lbs. has been raised 1 ft., how much work has been done? To raise the load that distance, how far has the effort travelled? What should be the effort?

CONCLUSION.—The mechanical advantage should be .....

4th Part.—Will the mechanical advantage be this? Give reasons for your answer.

Load the model crane and find what effort is actually required just to raise the load. Put the results in a table as shown below.

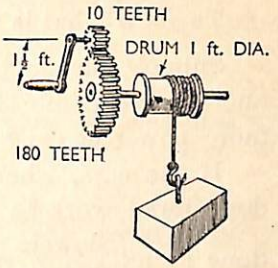
Useful load	Effort	Mech. adv. $= \frac{\text{Useful load}}{\text{Effort}}$	Efficiency $= \frac{\text{Mech. adv.}}{\text{Vel. ratio}} \times 100$

Repeat the experiment twice, adding an equal load each time and complete the table.

CONCLUSION.—The mechanical advantage is not .... because .....

Questions.

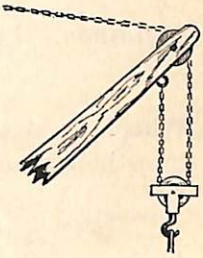
1. The wheelwork of a crane is shown here



(*a*) Calculate the velocity ratio.

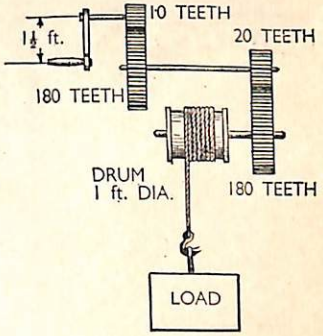
(*b*) To raise a load of 810 lbs., an effort of 20 lbs. weight is required. Find the mechanical advantage and the efficiency.

2. Sometimes the load chain passes under a single, movable pulley (snatch block, it is called) as shown. Using the dimensions of the above crane, calculate the velocity ratio.



3. (*a*) Calculate the velocity ratio of the crane if its wheelwork is as shown.

(*b*) Calculate the effort required to raise a load of 7,290 lbs. if the efficiency is 60 per cent.



HORSE POWER.

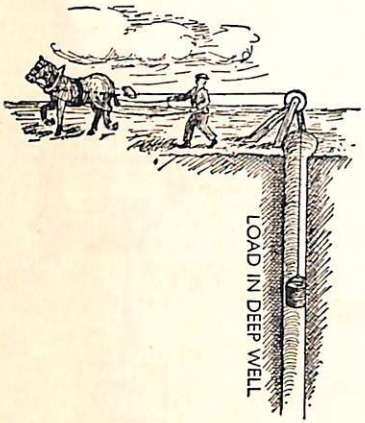
To show what is meant by horse power.

Suppose one motor can climb a hill at 40 miles per hour while another can climb the hill at only 20 miles per hour, which is the more powerful car?

If the cars, when loaded, are of equal weights, which car has done more work? More powerful, then means that the work is done at a { slower / faster } rate.

Definition.—**Power means the rate of doing work.**

When the steam engine was invented, people naturally wanted to know how many horses could be replaced by the engine. James Watt, the inventor, solved the question by experiment in this way.



The horse, Watt found, could raise 100 lbs. weight at a speed of $2\frac{1}{2}$ miles per hour. Calculate how many feet the load was raised in 1 minute. How much work was done per minute? As an allowance for the extra work the horse must have done in overcoming friction, Watt supposed that half as much work again had been done. Find the total work done per minute. This is known as one horse power.

Definition.—**One horse power means that .... foot pounds of work are done per minute.**

Questions.

1. Define power.

2. What is meant by one horse power?

3. A load of 16,500 lbs. is raised 20 ft. in 2 minutes. What horse power is required?

4. What load can be raised a height of 100 ft. in $\frac{1}{2}$ minute, if 12 horse power is available to do so?

5. A crane can raise a load of 12 tons to a height of 25 ft. in 4 minutes. What horse power is required to do so?

6. What horse power is required to pump 264 gallons of water per minute to a height of 50 ft., if only 80 per cent. of the work done by the pump is useful work? (1 gallon of water weighs 10 lbs.)

GEARING. THE MOTOR CAR.

Figure 1 shows the usual position of the gear box in a motor vehicle, while Fig. 2 shows the gear box itself and the gear change lever.

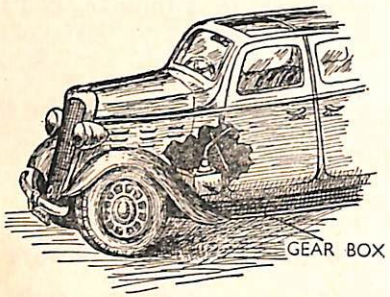


FIG. 1

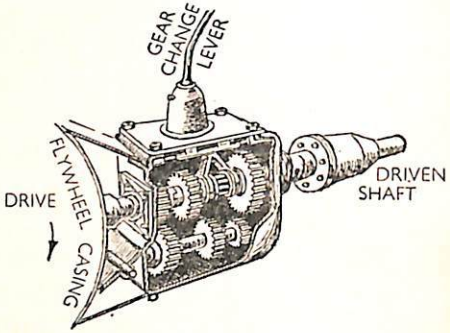


FIG. 2

The engine makes the driving shaft revolve. When the driving shaft causes the driven shaft to revolve in the same direction, the rear wheels revolve and the vehicle moves forward.

To study a three speed gear box.

In moving a vehicle on a level surface, what does the effort overcome? When the vehicle begins to climb, what other work must be done? In climbing, then, the load becomes { greater. / less. } To deal with this load, toothed wheels (the gear box) are used.

1st Part.—Neutral. When the driving shaft is made revolve by the engine, pinion **A** revolves with it. **A** is always in mesh with **B** and thus the layshaft revolves. Does the driven shaft revolve? Do the rear wheels turn? Does the vehicle move?

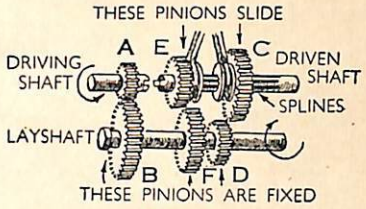


FIG. 3

A pinion wheel has 10 teeth. **D** pinion wheel has 15 teeth.
B ,, ,, ,, 30 ,, **E** ,, ,, ,, 24 ,,
C ,, ,, ,, 30 ,, **F** ,, ,, ,, 24 ,,

2nd Part.—1st gear. If **A** (Fig. 3) turns six times, how often does **B** turn? In what direction does **B** turn? The layshaft thus turns at a .... of the speed of the driving shaft.

(Note.—The driven shaft has grooves or splines along it (Fig. 4) and the pinions fit into these so that the shaft must turn with the pinions and yet the pinions can be moved along the shaft. The pinions are moved with the gear lever.)

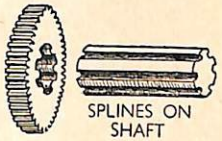


FIG. 4

Pinion **C** is now moved along the shaft till it meshes with pinion **D** (Fig. 5). How many turns will **C** make, if **A** makes six? The driven shaft thus turns at a .... of the speed of the driving shaft and in the {same / opposite} direction. The vehicle thus moves {slowly / quickly} forward and thus a {greater / less} load can be overcome.

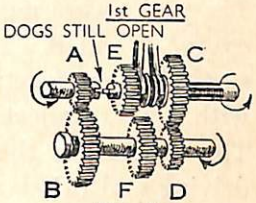


FIG. 5

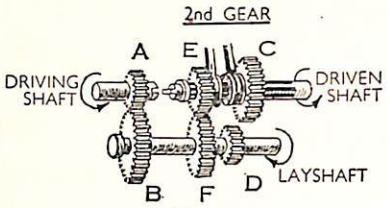


FIG. 6

3rd Part.—2nd gear. Pinion **C** is now pushed away from **D** and at the same time **E** is moved until it meshes with **F** (Fig. 6). How many times will the driven shaft turn now, if the driving shaft turns six times? The speed of the driven shaft, and consequently of the vehicle, is {increased / decreased} but the load which can be overcome is {increased. / decreased.}

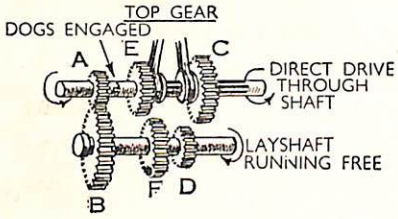


FIG. 7

4th Part.—3rd or top gear. Pinions are not used in this case. The pinions are moved with the gear lever so that none are in mesh except **A** and **B**. This time, however, the 2nd gear pinion is moved so that the projections (called dogs) fixed to one side of it, engage with similar projections fixed to pinion **A** on the driving shaft (Fig. 7). The shafts are thus locked together. What is the speed of the driving and driven shafts now? The vehicle thus moves still more {quickly / slowly} but a {greater / less} load can be overcome.

ANSWERS.

Questions, Page 8.

3. (*a*) ·03 ins.; (*b*) 136·9 ins.
4. (*a*) 47·8 ins.; (*b*) 1 lb.

Questions, Page 14.

3. (*b*) 10 ins.
4. 2 lbs.
5. 6 sts.
6. $2\frac{1}{2}$ lbs.
7. (*a*) 40; (*b*) 35; (*c*) 20; (*e*) 0.

Questions, Page 28.

3. (*a*) 5; (*b*) $\frac{1}{2}$.
5. 60 lbs. weight.
6. (*a*) $\frac{1}{3}$ cwt.; (*b*) 3; (*c*) $\frac{2}{3}$ cwt.; (*d*) $\frac{3}{2}$.
8. 12 tons weight.

Questions, Page 34

8. 3 lbs. weight.
9. $1\frac{1}{2}$ cwts.
10. $\frac{11}{24}$ cwt.; $\frac{19}{24}$ cwt.
11. 120 lbs.
12. 103 lbs. per sq. in.
13. $\frac{1}{5}$ ft. from centre of larger plate.

Questions, Page 41.

3. (*a*) 13·2 lbs. weight; (*b*) 5 lbs. weight; (*c*) 10·9 lbs. weight.
4. (*a*) 40 lbs. weight; (*b*) 50 lbs. weight.
5. (*a*) 68°; (*b*) 47°.
6. 725 tons weight.
7. 83°.
8. 94 lbs. weight.
9. 20 lbs. weight.

Questions, Page 46.

2. 158°; 72°; 130°.
3. 11·6 tons weight; 13·9 tons weight.
4. 9 tons weight; 15 tons weight.
5. 45 tons weight; 41·2 tons weight.
6. 5 cwts.; 4 cwts.
7. 3·7 tons weight; 3·3 tons weight.
8. Over 1 ton.

Questions, Page 48.

2. $6\frac{1}{2}$ lbs. weight.
3. 17·8 lbs. weight.

Questions, Page 52.

1. 9 st.; 3 st.
2. $\frac{3}{4}$ cwt.; 1 cwt.
3. 18 lbs.; 48 lbs.
4. $\frac{1}{3}$ weight; $\frac{2}{3}$ weight.
5. (*a*) $\frac{1}{4}$ ton; $2\frac{3}{4}$ tons.
   (*b*) $\frac{1}{2}$ ton; $2\frac{1}{2}$ tons.
   (*c*) $1\frac{1}{2}$ tons; $1\frac{1}{2}$ tons.
6. (*a*) $20\frac{1}{4}$ tons; $22\frac{3}{4}$ tons.
   (*b*) $20\frac{1}{2}$ tons; $22\frac{1}{2}$ tons.
   (*c*) $21\frac{1}{2}$ tons; $21\frac{1}{2}$ tons.
7. 4 ft.

Questions, Page 59.

1. (*a*) 700 ft. lbs.; (*b*) 840 ft. lbs.; (*c*) 42 ft. lbs.; (*d*) 1960 ft. lbs.; 560 ft. lbs.; (*e*) 1100 ft. lbs.

Questions, Page 62.

1. (*c*) 1; (*d*) 1; (*f*) $\frac{3}{4}$; (*g*) 75 per cent.
2. 125 lbs. weight.

Questions, Page 65.

1. (*a*) 3 ; (*b*) 3 ; (*c*) 20 lbs. weight ; (*d*) 80 per cent.
2. (*a*) 5 ; (*b*) 12 lbs. weight ; (*c*) 50 lbs. ; (*d*) 5 ; (*e*) $83\frac{1}{3}$ per cent.
3. 40 lbs. weight.
4. 800 lbs. weight.
5. 2 ft.

Questions, Page 68.

1. (*a*) 4 ; (*b*) 4 ; (*c*) 3 ; 75 per cent.
2. 100 lbs. weight.
3. (*d*) $4\frac{4}{5}$; 80 per cent.
4. 50 lbs. weight.

Questions, Page 71.

2. (*a*) 24 ; (*c*) 960 lbs.

Questions, Page 76.

3. (*a*) 40 lbs. weight ; (*b*) 80 lbs. weight.
4. $\frac{1}{4}$ ton weight.
5. (*a*) 20 lbs. weight ; (*b*) 50 lbs.
6. 4 ft.
7. 2 ft.

Questions, Page 83.

1. (*c*) $\frac{2\pi r.}{p}$
2. (*a*) $\frac{2\pi R}{P}$; (*b*) $\frac{2\pi R}{P}$.
4. (*a*) 176 ; 176. (*b*) 88 ; 50 per cent.
5. 1320 lbs.

Questions, Page 90.

2. 215 lbs. weight; 150 lbs. weight.
3. 190 lbs. weight; 300 lbs. weight; 255 lbs. weight.
4. 210 lbs. weight; 350 lbs. weight.
5. (*a*) 2·5 tons weight; 3·5 tons weight.
   (*b*) 50 tons; (*c*) 12 sq. ins.; 17 sq. ins.

Questions, Page 93.

2. 70.

Questions, Page 97.

1. (*a*) 54; (*b*) $83\frac{1}{3}$ per cent.
2. 108.
3. (*a*) 486; (*b*) 12·5 lbs. weight.

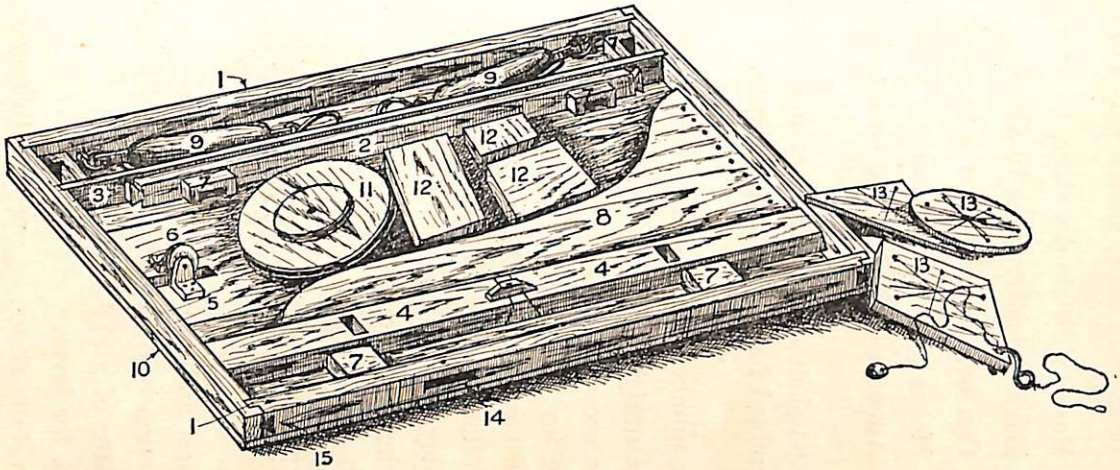
Questions, Page 99.

3. 5 H.P.
4. 1980 lbs.
5. $5\frac{1}{11}$ H.P.
6. 5 H.P.

APPARATUS.

The apparatus shown in the following sketch is simple, easy to construct and of a type that has been successfully used in various centres.

MECHANICS TRAY.



The benefits of using such a tray are as follows :—

(*a*) Easy to distribute, store, move and check.

(*b*) Easy and interesting to assemble.

(*c*) Can be employed over a range of experiments.

(*d*) Makes any room suitable for the teaching of mechanics.

(*e*) Allows each individual to move at his own speed.

In the sketch, the parts are numbered to show how they may be assembled for various experiments.

The numbered parts are :—

1. The uprights.
2. The cross beam.
3. The lever.
4. The base plates for uprights.
5. Friction board and inclined plane.
6. Pulley for inclined plane.
7. Sockets for uprights.
8. Bell crank lever.
9. Spring balances.
10. Underside of tray (used as board for concurrent forces. See Fig. 4.)
11. Wheel and axle.
12. Friction boards, each with one different face.
13. Centre of gravity laminae.
14. Slot for lever.
15. Dovetails at top of uprights to receive beam (2).

When erected as in Fig. 1, the following experiments can be worked.

(*a*) Force experiments, parallel forces, wheel and axle, pulleys and centres of gravity.

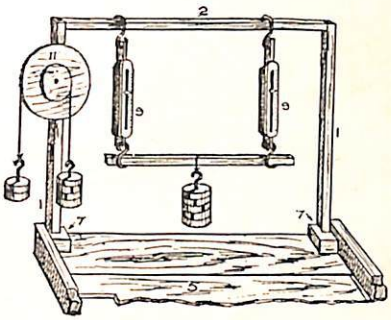


FIG. 1

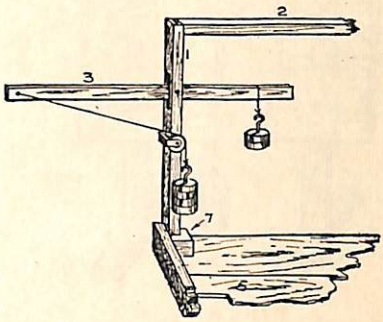


FIG. 2

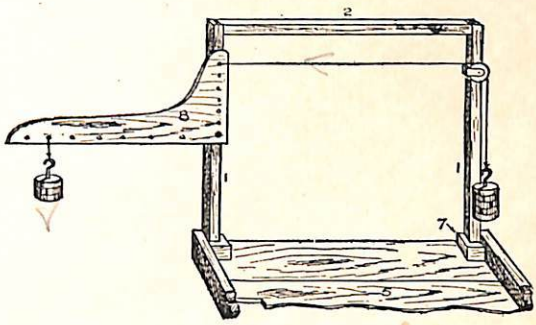


FIG. 3

When erected as in Fig. 2, it is suitable for experiments in moments.

In Fig. 3, the bell crank lever is shown being operated.

In Fig. 4, the apparatus is arranged for concurrent forces and extra centre of gravity experiments.

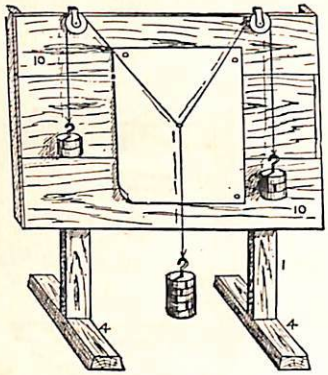


FIG. 4

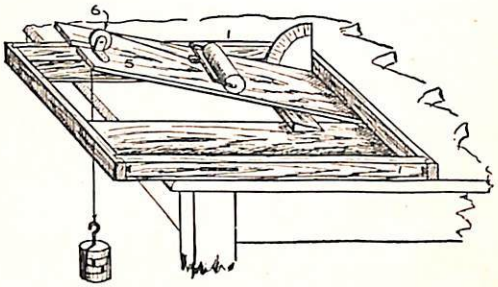


FIG. 5

Fig. 5 shows the friction board hinged up and in use as an inclined plane.

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